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THE BEHAVIOR IN SOILS AND PLANTS OF TRACES OF STRONTIUM, CESIUM, RUTHENIUM AND ZIRCONIUM[1]

V. M. Klechkovskii and I. V. Gulyakin,[2] *K. A. Timiryazev Agricultural Academy*

In recent years an interest has developed in investigating the behavior in plants and soils of small quantities of some elements which previously had not attracted the attention of agricultural chemists and plant physiologists. Among such elements are strontium, ruthenium, cesium and some others occupying places in the middle of Mendeleyev's periodic system. This interest is related principally to the involvement in the biological cycle of substances in nature, and to the possible paths of migration of radioactive nuclides formed when the nuclei of heavy elements disintegrate. It is natural that, from this point of view, the long-lived elements, such as strontium-90, cesium-137, and others should be of the greatest importance.

In experiments with the radioactive isotopes of strontium, yttrium, zirconium, niobium and cerium, Jacobson and Overstreet (6) observed that traces of strontium had the highest rate of intake by the organs of plants located above ground. Vlamis and Pearson (16) confirmed that zirconium accumulates predominantly in the roots and in small quantities in the organs of peas above ground. Rediske and Selders (12) and Rediske and Hungate (14) found that the ratio between the concentration of radioactive strontium in those parts of the plants aboveground to its concentration in the soil was greater than unity; in experiments carried out by Neubauer's method, barley absorbed about 2% of the radioactive strontium contained in the soil.

In experiments with radioactive yttrium, the analogous ratio and percent of absorption were far less (13). There is extensive similarity between strontium and calcium in their behavior in plants. In Menzel's experiments (7) the strontium intake in plants was inversely proportional to the content of exchangeable calcium, while the intake of cesium was inversely proportional to the amount of soil potassium accessible to plants.

Neel, Olafson et al. (8) and Romney et al. (15) studied the intake of radioisotopes of strontium, ruthenium, cesium and cerium and observed the highest rate of intake and accumulation of strontium in the vegetative organs; they noted the effect of the soil reaction and of the exchangeable calcium content in soil on the intake of strontium by plants. Nishita, Kowalewsky and Larson (9) showed that the mineralogical composition of the soil affects the intake of traces of strontium, cesium and ruthenium. The mineralogical composition is manifested in the relative strength with which the different fission products are retained in the adsorbed state. Nishita et al. (10, 11) recently reported observations on the effect of organic substances on the assimilation of strontium-90 by barley and tomato plants.

For several years we have been doing research on the behavior of fission products in soils and in plants; some of the results of this research have been published (1–5). The experiments were done both with the radioactive isotopes of separate elements and also with nonseparated fission products. The various forms of radiochemical composition and its change with time introduce complications into the general behavior picture of such radioactive nuclides in an agricultural chemical experiment. However, certain results of experiments with nonseparated mixtures of fission products are of interest, especially when they make possible the comparison of data characterizing the specificity of the behavior in similar systems of the individual components entering into such mixtures.

In addition to the specific peculiarities caused by the fact that each of the fission products of long and medium life belongs to a certain chemical group, there exist other causes resulting in unique phenomena which we will discuss subsequently. These phenomena are related primarily to the extremely small quantities of the substance on which the observations were made; if the radioactivity of fission products obliges us

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[1] This report was presented at the International Conference on the Application of Radioisotopes in Scientific Investigations (Paris, 1957).

[2] E. V. Yudintseva, A. V. Korovkina, G. N. Tselishcheva and L. N. Sokolova worked on results covered by this paper.

Table 1

Content of Cs^{137}, Sr^{90}, Ru^{106}, and Zr^{95} in mature wheat plants (in thousands of counts per minute per gram of dry material). The plants were placed for 24-hour periods in solutions of radioisotopes during the entire growing period

Part of plant	Cs^{137}	Sr^{90}	Ru^{106}	Zr^{95}
Grain	29.1	2.3	0.03	0.02
Chaff	143.6	16.9	1.0	0.13
Upper leaves	495.2	102.4	3.2	0.70
Lower leaves	323.4	124.9	1.40	0.88
Upper half of stem	178.6	33.9	0.70	0.10
Lower half of stem	123.4	32.7	1.00	0.20
Entire above-ground portion (average)	146.3	33.2	0.70	0.20
Roots	807.0	56.3	368.50	31.60

Table 2

Content of the radioactive isotopes Cs^{137}, Sr^{90}, Ru^{106}, and Zr^{95} in mature wheat plants (in thousands of counts per minute per gram of dry material). The plants were placed for 24-hour periods in solutions of radioisotopes during the period from the phase of maximum stem development until the end of the experiment

Part of plant	Cs^{137}	Sr^{90}	Ru^{106}	Zr^{95}
Grain	34.5	1.2	0.02	0.02
Chaff	188.8	21.4	0.40	0.20
Upper leaves	674.7	115.2	1.80	0.80
Lower leaves	365.4	134.6	1.60	0.70
Upper half of stem	191.6	37.7	0.60	0.60
Lower half of stem	102.4	32.4	0.40	0.60
Entire above-ground portion (average)	159.1	35.5	0.40	0.30
Roots	441.1	65.7	152.70	63.20

to attach importance to the study of their behavior when they are included in the biological cycle, such radioactivity also makes possible the detection of traces of the corresponding elements.

An additional factor causing unusual processes taking place with radioactive fission products is the presence among the latter of long-lived nuclides forming radioactive daughter nuclides on fission (such as $Sr^{90} \rightarrow Y^{90}$ or $Zr^{95} \rightarrow Nb^{95}$ etc.). The study of the peculiarities of behavior in soils and in plants of such short chains of radioactivity is not only important from the standpoint of methods (for such peculiarities should be considered in determining the content of such nuclides by their radioactivity), but it is also of general interest.

Intake and Distribution in Plants

When plants take in radioactive substances, sorption processes and mutual precipitation occur related to changes in the reaction of th nutrient solution and to the formation of precipitates. To reduce the role of these factors a much as possible, experiments in water cultur were carried out by the fractional nutritio method. The plants were placed temporarily i containers with a full nutrient mixture wher they received the necessary nutrients (withou the application of radioactive isotopes). During the experimental period, beginning at a definit time, the plants were transferred temporarily t other containers containing a tap-water solution of the trace component under study. After 2 hours in the radioactive solution the plants were again placed for one 24-hour period in containers with full nutrient mixture without the radioisotopes, and this process continued for the entire experimental period.

Tables 1 and 2 show typical data of one o the experiments with wheat. In the first series (Table 1) the plants were transferred (for 24 hours at a time) from the nutrient mixture to the solutions with radioisotopes Sr^{90}, Zr^{95}, Ru^{106}, and Cs^{137} during the entire period beginning with the transplanted seedlings (into containers of the growing medium) and ending with their maturity. The concentration of radioactive isotopes was 50 μc. per liter. With this dose, and under the conditions described here, there was no evidence of radiation damage to the plants.

In the second series (Table 2) the plants were placed (for 24 hours at a time) in solutions of the radioisotopes at maximum stem development until the end of the experiment.

Tables 1 and 2 show a sharp difference in the ability of traces of strontium and cesium on the one hand and of ruthenium and zirconium on the other to penetrate via the roots into the above-ground organs of the plants. In this respect a very characteristic index is the ratio between the average activity (per gram of dry material) of the above-ground tissue and that of the roots (also per gram of dry material) for the first and second series of experiments with these elements:

		Sr^{90}	Cs^{137}	Zr^{95}	Ru^{106}
Ratio between the average activity of the above-ground tissue and of that of wheat roots[3]	I	0.59	0.18	0.006	0.002
	II	0.54	0.36	0.005	0.002

The root system appeared to be a barrier against penetration into the above-ground organs of traces of zirconium and ruthenium. This does not occur with traces of strontium and cesium.

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[3] I = ratio calculated according to the data of Table 1; II = that calculated according to the data of Table 2.

It is curious that the ratio of the quantity of strontium in the roots to that in the above-ground portion of the plants was almost the same in the two series of experiments (I and II); the same thing was observed in experiments with ruthenium and zirconium. For cesium the ratio of activity of the above-ground portion to that of the roots was higher in the second series—when the plants entered the experiment at a later phase of development, the beginning of maximum stem development.

Table 3 shows the distribution of traces of cesium, strontium, ruthenium, and zirconium expressed as a percentage of the total content of each of these elements calculated for a single plant. A clear difference appears between the distribution of cesium and strontium on the one hand and ruthenium and zirconium on the other. In experiments with strontium and cesium the radioisotope content in the roots varied between 6 and 17% (of the total content of a plant); in experiments with ruthenium and zirconium the quantity in the roots amounted to 83 to 95%.

While the distributions between the roots and the above-ground portion of strontium and cesium were mutually similar differing considerably from those of zirconium and ruthenium, the situation is quite different with respect to the distribution of the same elements between different organs of the above-ground portion of wheat plants. A relatively large percentage of the trace of radioactive cesium is taken in by the reproductive organs and detected in the grain. This may be seen from the following comparison:

		Cs^{137}	Sr^{90}	Zr^{95}	Ru^{106}
Ratio between the activity of the grain and the average activity of the above-ground portion of the wheat plant	I	0.20	0.07	0.10	0.04
	II	0.21	0.03	0.06	0.04

The difference between the ability of strontium and cesium to accumulate in the reproductive organs of wheat appears to be very noticeable as early as the end of maximum stem development. The ratio between activity of the dry substance of the spikes and that of the leaves in this phase was 0.08 for Sr^{90} and 0.7 for Cs^{137}. It must be noted, however, that in experiments with all four elements (Sr, Cs, Ru and Zr), the smallest content in all cases, both relatively and absolutely, was in the grain. This peculiarity of distribution in plants, that is, preponderant accumulation in the vegetative organs and a smaller intake into the grain, is evidently a general characteristic of a majority of elements to which the fission products belong (8). This is supported by the fact that distribution of a type similar to that in experiments with wheat and other plants was observed in the overwhelming majority of experiments done with nonseparated mixtures of fission products.

TABLE 3

Distribution of Cs^{137}, Sr^{90}, Ru^{106}, and Zr^{95} in mature wheat plants as percentages of the total content of the isotope in the plant

Part of plant	Cesium-137		Strontium-90		Ruthenium-106		Zirconium-95	
	I	II	I	II	I	II	I	II
Grain	4.8	5.9	1.8	1.0	0.1	0.2	0.5	0.4
Chaff	12.4	13.3	6.4	6.7	0.8	1.2	1.2	1.0
Leaves	27.4	37.0	43.6	45.7	1.5	4.9	8.6	3.6
Stem	38.4	34.2	41.0	40.2	1.9	4.9	7.0	7.6
Roots	17.0	9.6	7.2	6.4	95.7	88.8	82.7	87.4

Note: 1. The plants were placed in the solution of radioisotope (at some time) during the entire growing period; 2. same, but only from the beginning of the phase of maximum stem development.

The relatively high capacity of cesium to move from the vegetative organs into the reproductive organs accumulating in the seeds is also detected with foliar application of traces of cesium-137. In experiments where a cesium solution was applied to one of the leaves of sunflower or kidney bean, the activity moved at a fairly high rate into other, unprocessed leaves and significant activity was detected in the grain. The radioisotopes of strontium and ruthenium moved out of the leaf where it was applied to the other parts of the plant at a relatively far lower rate. This can be judged by the data given in Table 4.

In Table 4 the radioisotope content in the untreated portions of bean plants is expressed as the value of the ratio in percent of the activity per gram of dry substance of the respective organ to the activity of the total quantity applied to the treated leaf. This index of "specific activity" for strontium is tens and hundreds of times lower than for cesium and, as a rule, noticeably lower than for ruthenium. Similar data from the experiment with sunflower, given in

TABLE 4

Content of radioisotopes Cs^{137}, Ru^{106}, and Sr^{90} in different parts of bean plants three weeks after being applied to the third leaf; specific activity per gram of dry substance of the untreated portions of the plants expressed as a percentage of the total quantity applied to the third leaf

Part of plant	Cs^{137}	Ru^{106}	Sr^{90}
Leaves below treated leaf	0.03	—	0.001
Leaves above " "	1.05	0.056	0.004
Main stem above treated leaf	0.65	0.037	0.003
Beans of main stem	0.74	0.005	0.002
Leaf of a shoot emerging from third (treated) leaf	2.74	0.026	0.011
Beans on this shoot	2.38	0.011	0.001

TABLE 5

Content of the radioactive isotopes Sr^{90} and Cs^{137} in different parts of a mature sunflower plant; specific activity per gram of dry substance of the untreated parts of the plant expressed as a percent of the total amount applied to the eighth leaf before the beginning of formation of the anthodium

Parts of plant	Cs^{137}	Sr^{90}
Corolla	0.02	0.000
Seed coat	0.06	0.001
Pulp of the anthodium	0.14	0.002
Flowers	0.13	0.003
Stem above the treated leaf	0.02	0.002
Leaves above treated leaf (17th to 20th leaves)	0.14	0.008
" " " " (13th to 16th leaves)	0.17	0.003
" " " " (9th to 12th leaves)	0.15	0.010
" below " " (6th to 7th leaves)	0.13	0.056
" " " " (1st to 5th leaves)	0.11	0.027
Stem below treated leaf	0.01	0.002

Table 5, also show the far smaller ability of strontium to translocate in plants with foliar application as compared to cesium.

Thus, both with uptake from a water solution through the roots and with foliar application, traces of cesium appear to be the most mobile; this element is comparatively easy and is more or less evenly distributed among the various organs of the plant. The behavior of traces of strontium is much like that of cesium, provided the uptake is from solution and via the roots. Strontium, like cesium, does not accumulate in the roots and penetrates with ease from the roots to the above-ground organs of the plant. However, under these conditions strontium is translocated from the vegetative to the reproductive organs of the plant in comparatively smaller amounts than is cesium. With foliar application of these elements, strontium proves to be far less capable of translocation between organs than cesium. The high mobility of traces of cesium in plants as compared to the mobility of other fission products is thus especially evident with foliar uptake.

Uptake by Plants of Traces from the Soil

The previous examples characterize the behavior of traces of strontium, cesium, ruthenium and zirconium in plants without the interference of processes taking place in the soil. Under natural conditions, radioactive fission products can enter plants both through the leaves and through the roots. In the latter case the behavior of the respective elements in soils takes on substantial importance.

Investigations made with undifferentiated mixtures of fission products and with individual representatives of this group of substances showed that soils have a clearly expressed capacity for the sorption of these trace elements which surely must influence their uptake by plants. Substantial importance is attached to the tenacity with which sorbed elements are retained by the soil and to their capacity for desorption and translocation in the soil. Experiments with plants grown on soils show that under the influence of these factors there is a change in the order of the different elements ranked according to the relative rate of their uptake by plants and their accumulation in the crop.

Table 6 shows the uptake of strontium, cesium, ruthenium and zirconium in wheat plants grown in pot experiments on soil containing 50 μc. of radioactive isotopes of these elements per kg. of soil with uniform distribution throughout. The experiment was set up with a medium clay loam from the Moscow farm of the Timiryazev Agricultural Academy (adsorption capacity, 13.3 me. per 100 g. of soil; hydrolytic acidity 2.6 me.; pH of salt extract, 5.8).

In Table 6 the content of radioisotopes in the different parts of wheat plants is shown in thousands of impulses per minute per gram of dry substance. For comparison, similar data on the content of strontium, cesium, ruthenium and zirconium in wheat with uptake from an aqueous solution at a concentration of 50 μc. per liter are also given.

While cesium is the element accumulated in the largest quantities by plants grown on an aqueous medium, with uptake from the soil an especially sharp decrease is observed in the amount of cesium arriving in the above-ground organs of the plant. Strontium is more conspicuous by the amount of its accumulation both in straw and in grain. Evidently, traces of strontium sorbed by the soil are less tenaciously held by it in the adsorbed condition than are traces of cesium. With respect to the distribution of strontium, cesium, ruthenium and zirconium among the different parts of the crop, the same distribution occurs both with an aqueous medium and with growth on soil: the smallest amount of radioisotopes of these elements is contained in the grain and the greatest amount in the straw. In pot experiments with 50 μc. per kg. of soil it was not possible to detect any uptake of ruthenium or zirconium in the grain. A fivefold increase in the amount of zirconium in the soil with local application at depths of 5 and 15 cm. was accompanied by some increase in the content of zirconium-95 in the straw and chaff and its appearance in relatively small amounts (as judged by radioactivity) in the grain.

Differential uptake by plants of traces of the elements being studied was observed, depending on the properties of the soil. Uptake is influenced by the soil texture, calcium content, degree of cation saturation, and soil reaction. Liming acid soil can decrease the uptake by plants primarily of traces of radiostrontium. The application of fertilizers also affects the uptake of radiostrontium and other fission products.

In pot experiments on acid clay loam from the Moscow Agricultural Experiment Station of the Timiryazev Agricultural Academy (adsorption capacity 11.5 me. per 100 g. of soil; hydrolytic acidity 6.3 me.; pH of salt extract 4.8) a conspicuous increase was observed in the uptake of traces of strontium and especially of cesium under the influence of a nitrogenous fertilizer. Potassium fertilizer, on the contrary, decreases the uptake of cesium and its accumulation both in the vegetative organs and in the grain. Tables 7 and 8 illustrate this idea. The fertilizers in this experiment were applied as salts: NH_4NO_3, KCl, and $Ca(H_2PO_4)_2$ at the rate of 0.5 g. N, K_2O and P_2O_5 per pot, mixed with 3.5 kg. of soil. The amount of radioisotopes (Cs^{137} and Sr^{90}) was 250 μc. per pot.

TABLE 6

Content of the radioactive isotopes Cs^{137}, Sr^{90}, Ru^{106}, and Zr^{95} in wheat plants with uptake from water culture and from soil (in thousands of counts per minute per gram of dry material)

		Strontium-90	Cesium-137	Ruthenium-106	Zirconium-95
Uptake from soil	Grain	0.10	0.02	0.00	0.00
	Chaff	0.60	0.10	0.03	0.01
	Straw	1.65	0.28	0.08	0.04
Uptake from water solution	Grain	2.3	29.1	0.03	0.02
	Chaff	16.9	143.6	1.00	0.13
	Straw	54.1	208.4	1.13	0.36

TABLE 7

Effect of fertilizers on the content of Cs^{137} in oats (in thousands of counts per minute per gram of dry material)

Part of plant	Treatment							
	O	K	N	NK	P	PK	PN	PNK
Leaves at stooling stage	0.8	0.2	10.9	1.7	0.9	0.1	9.2	1.9
Leaves at stage of maximum stem development	1.5	0.3	18.3	2.2	1.7	0.3	13.2	1.2
Mature plant:								
Grain	0.5	0.04	3.0	0.6	0.3	0.01	2.5	0.5
Straw	3.5	0.3	6.9	0.9	1.1	0.2	5.5	1.2

TABLE 8

Effect of fertilizers on the Sr^{90} content of oats (in thousands of counts per minute per gram of dry material)

Part of plant	Treatment							
	O	N	P	NP	K	NK	PK	NPK
Leaves at stooling stage	82.2	137.6	109.7	143.2	117.4	133.1	105.5	146.9
Leaves at stage of maximum stem development	83.8	122.9	77.9	138.2	73.7	107.5	74.9	111.2
Mature plant:								
Grain	11.8	9.7	12.0	8.5	11.9	8.6	12.4	9.1
Straw	64.4	149.3	86.6	157.8	67.8	108.1	76.2	133.3

Table 7 shows that the application of potassium fertilizer in all cases decreased the Cs^{137} content of straw and of grain, while the application of nitrogenous fertilizer increased it. The uptake of Sr^{90} changed less abruptly under the influence of fertilizers, but here, too, a tendency could be noted to increase the strontium content of the vegetative organs of oats under the action of nitrogenous fertilizer (Table 8). The content

TABLE 9

Change in ratio between the content of Sr^{90} and Cs^{137} in oat grain and straw under the action of fertilizers

	N	NP	NK	NPK	O	P	K	PK
Ratio $\frac{Cs^{137}\text{ in straw}}{Cs^{137}\text{ in grain}}$	2.3	2.2	1.5	2.4	7.0	3.7	7.5	20.0
Ratio $\frac{Sr^{90}\text{ in straw}}{Sr^{90}\text{ in grain}}$	15.4	18.6	12.5	15.6	5.5	7.2	5.7	6.1

TABLE 10

Content of Sr^{90} and Cs^{137} in plants (in thousands of counts per minute per gram of dry material)

Element and parts of harvest		Treatments[a]				
		Control	(Ca½)	Ca(2)	K(1)	K(2)
Wheat						
Strontium-90	Grain	24.5	11.7	8.3	14.6	14.2
	Straw	342	206	132	207	196
Cesium-137	Grain	0.9	0.3	0.4	0.05	0.04
	Straw	2.2	1.4	1.7	0.5	0.3
Peas						
Strontium-90	Grain	24.9	14.4	7.7	19.9	17.5
	Straw	825	721	492	851	828
Cesium-137	Grain	2.0	0.8	0.6	0.7	0.2
	Straw	6.4	2.2	1.6	1.5	0.7

[a] The quantity of lime applied is shown as proportion of hydrolytic acidity (neutralized?); K(1) = 1 g. K_2O per pot and K(2) = 1.9 g. K_2O per pot.

of strontium-90 in grain changed less under the action of fertilizers, while the differences in cesium content in grain (caused chiefly by the action of potassium fertilizer) were as great as those in the vegetative organs.

The distribution of cesium and strontium between the vegetative organs and the grain changed quite regularly under fertilizers. A comparison of these elements in grain and straw and calculation of the ratio between their activity in these crops give a very clear picture. In all treatments, which included nitrogenous fertilizer, the ratio between the content of cesium in straw and grain were considerably lower than in treatments without nitrogen. However, the ratio between the content of Sr^{90} in straw and grain under nitrogenous fertilizer changed in the opposite direction: it was two to three times higher in plants which had received nitrogenous fertilizer (Table 9).

Table 9 shows that the differences in distribution of cesium and strontium between grain and straw, when traces of these elements are taken up from the soil, is far more strongly expressed with a normal supply of nitrogenous nutrition to the plants. With a shortage of nitrogen these differences level out and become less regular.

On acid soils liming affects substantially the uptake of radiostrontium and certain other fission products. By increasing the content of calcium in the soil, liming decreases the ratio between strontium and calcium in the composition of the exchangeable cations and in the soil solution. However, the decrease in uptake of Sr^{90} under liming can hardly be attributed to this factor alone. In a number of experiments, liming the soil decreases the accumulation not only of traces of strontium but also of certain other elements which are not even analogs of calcium in the periodic system.

Experiments with wheat and peas on the same soil from the Moscow field experiment station of the Timiryazev Agricultural Academy are given in Table 10. These show that under liming there was a decrease in the uptake of Sr^{90} and Cs^{137}. Furthermore, a comparison of the action of lime and potassium fertilizers made it possible to see the specific effects on these two elements. Liming exerted a stronger influence on the uptake of strontium; potassium had the same effect on the uptake of cesium.

Application of decomposed organic matter (humus), especially on coarse sandy, loam, decreased the uptake of Sr^{90} and Cs^{137}. This decrease was greater for strontium than for cesium. The uptake of traces of ruthenium also, as a rule, decreased somewhat under enrichment by humus and liming. However, as a result of the generally small uptake of ruthenium (and also of zirconium) via the roots and into the above-ground organs of plants, the action of these factors does not develop as clearly as for strontium.

Sorption and Desorption in the Soil

A general characteristic of the behavior of strontium, cesium, and zirconium, and evidently most of the elements found in fission products, is a high rate of adsorption of them by the solid phase of the soil. Of the elements considered here, ruthenium is distinguished by the least complete sorption in soils. However, sharper differences in the behavior of these elements in soils appear in a comparison of their desorption capacities, that is, displacement from the adsorbed state into solutions of neutral salts.

Table 11 shows the results of experiments with three types of soils: chernozem, podzolic soil, and krasnozem. Half-gram soil samples were treated with 10 ml. of radioactive solutions. Samples were carefully mixed, allowed to stand and completely clear. A sample was then taken for measurement of the activity. A 10 me. of $CaCl_2$, KCl or $NaNO_3$ was added to the solution, and after a second shaking and standing another sample was taken for measurement of the activity. The data show that zirconium and ruthenium are displaced hardly at all into the $CaCl_2$ solution, cesium is most strongly displaced into the KCl solution, while the desorption of cesium was maximal in experiments with krasnozem and minimal in those with chernozem. This order is also retained when cesium is displaced by other salts. The displacement of strontium by calcium and sodium was complete in experiments with krasnozem; not quite as complete displacement of strontium was observed in experiments with podzolic soil and with chernozem if the displacement was carried out with sodium.

Data in Table 10 agree with the hypothesis that the sorption of traces of strontium and cesium by soils takes place by means of ionic-exchange adsorption. However, traces of adsorbed cesium are retained more tenaciously in the adsorbed state than are traces of strontium: evidently a part of the sorbed cesium is fixed in soils without exchange. The traces of zirconium and ruthenium adsorbed by the soil are in general incapable of being desorbed by the action of neutral salts. This is evidence of a mechanism of sorption of these elements by soils which differs from the ionic-exchange mechanism.

Thus, considering their incapability of being desorbed, zirconium and ruthenium behave the same way in soils. However, they differ strongly in the completeness with which they are adsorbed from solution in the original interaction with the soil. Zirconium is more completely sorbed than ruthenium, but this difference is more conspicuous in experiments with podzolic soil and chernozem and levels out somewhat in experiments with krasnozem, which sorbs maximal amounts of ruthenium.

TABLE 11

Adsorption of Sr^{90}, Cs^{137}, Zr^{95}, and Ru^{106} by soils, and desorption of adsorbed radioisotopes in neutral salt solutions

		Chernozem (Voronezh region)	Podzolic soil (Moscow region)	Krasnozem (Batumi)
Adsorption as per cent of content in original solution	Sr^{89}	74.4	70.3	91.2
	Sr^{90}	87.8	80.5	87.6
	Cs^{137}	93.3	94.9	95.6
	Zr^{95}	95.6	95.9	61.1
	Ru^{106}	30.4	15.4	40.4
Displaced into $CaCl_2$ solution as percent of that sorbed	Sr^{89}	100	97.4	100
	Sr^{90}	75.5	93.9	100
	Cs^{137}	3.2	12.9	32.6
	Zr^{95}	none	3.6	none
	Ru^{106}	none	none	none
Same, into $NaNO_3$ soln.	Sr^{90}	60.0	73.0	100
	Cs^{137}	6.9	17.1	30.3
Same, into KCl solution	Cs^{137}	20.8	37.2	59.5

For a more detailed comparative characterization of the sorptive capacity of soils with respect to traces of strontium, cesium and ruthenium, the following method was used. A series of soil samples of increasing weight were treated in centrifuge tubes with a definite volume of radioactive solution. After careful mixing of the soil with the solution they were centrifuged and a sample of the solution was removed for measurement of the radioactivity. The results are expressed as percentages of the activity of the original solution. In this way the so-called "adsorption curve" is found, showing the course of the change of the remaining activity of the solution with an increase in the mass of the sorbent (T) with a constant volume of solution (ZH), that is, with a change in the ratio T:ZH. The interval of this ratio is selected in such a manner that some part of the experimental points of the adsorption curve falls in a region in which the value of the residual activity is about 40 to 60%.

For each point on such an adsorption curve a calculation is made of the ratio (K) between the specific activity of the solid phase and that of the solution after sorption:

$$K = \frac{100 - x}{x} \cdot \frac{v}{m} \qquad (1)$$

in which x is the residual activity of the solution as a percentage of the original value; v is the volume of the solution; m is the weight of the sample of sorbent; and K is the coefficient characterizing the distribution of the trace component between the sorbent and the solution. In many cases the values, calculated by equation (1), of the coefficient of distribution prove to be about the same over all or most of the adsorption curve. As an example let us take the data obtained in an experiment with podzolic clay loam from the Forestry Station of the Timiryazev Agricultural Academy of Moscow (Table 12).

TABLE 12

Value of the coefficient K according to equation (1). Experiment with peat podzolic soil from the K. A. Timiryazev Agricultural Academy

v (in ml.)	m (in g.)	Value of K	
		Sr^{90}	Cs^{137}
10	0.01	592	683
10	0.02	664	1285
10	0.03	673	1141
10	0.04	532	1114
10	0.05	529	1148
10	0.07	500	1086
10	0.09	483	1075
10	0.10	551	1226
Average		565	1095

TABLE 13

Average value of the coefficient K, calculated according to equation (1), for adsorption curves of traces of strontium, ruthenium, and cesium in experiments with different soils

Soil sample		Value of K		
		Sr^{90}	Ru^{106}	Cs^{137}
Chernozems	1	1608	12	4655
	2	1182	12	3017
Podzolic clay loam	1	869	10	2287
	2	562	6	1810
	3	565	8	1096
Krasnozem		625	59	1192

TABLE 14

Average values, calculated according to equation (1), of the coefficient K for adsorption curves of cesium

Soil sample		Concentration of KCl			
		0	0.01 N	0.1 N	0.5 N
Chernozems	1	4655	1182	138	25
	2	3017	687	84	14
Podzolic clay loam	1	2287	509	44	11
	2	1810	284	34	10
	3	1096	125	16	8
Krasnozem		1192	95	25	11

The average value of the coefficient calculated by equation (1) may serve as a quantitative index of the relative sorptive capacity of the soil for this trace component when it is sorbed from a solution of one composition or another. Table 13 shows the average values of this coefficient calculated according to the adsorption curves of Sr^{90}, Cs^{137}, and Ru^{106} for all the chernozem samples, three podzolic sandy loams, and one krasnozem.

These data very clearly demonstrate the smaller sorbability of ruthenium as compared to strontium and cesium, and the greater sorbability of cesium as compared with strontium. These data show that krasnozem is distinguished by a high sorptive capacity for ruthenium and that its sorptive capacity for traces of strontium and cesium is about the same as that of podzolic clay loam.

By using the adsorption curves and calculating the average value of the coefficient of distribution (by equation 1) a quantitative characterization may be given of the desorbing action of salts and of the effects of other factors on the sorption of radioactive trace components of soils. This can be illustrated by experiments, the results of which are shown in Table 14. This shows a study made of the action of KCl on the sorption of traces of cesium.

In a number of cases more or less regular changes are observed in the value of the coefficient of distribution calculated according to equation (1), with a change in the ratio between the mass of the soil and the volume of the radioactive solution. These cases are especially typical for conditions in which the original solution contains not one trace component, but two or more which differ in their sorbability. The changes in the value of this coefficient may be attributed to other causes brought about by properties of the soil and by the composition of the original solution from which adsorption took place. An analysis of the influence of each may help to clarify the peculiarities characterizing the specificity of the reaction between traces of radioactive substances and the soils.

Shifts in the Ratio Between Sr^{90} and Y^{90} in Reactions with Soils and Uptake by Plants

One of the specific peculiarities of radioactive fission products is the presence among them of genetically related radioactive nuclides. If two such nuclides belong to elements differing sharply n chemical properties, the possibility arises of partial separation of mother and daughter nuclides in the reaction with the soil and in the uptake by, and translocation in, plants.

This question was investigated in the series $Sr^{90} \rightarrow Y^{90}$. In experiments with soils the following method was used: Soil samples weighing 0.5 or 1 gram were treated in a centrifuge tube with a solution containing $Sr^{90} + Y^{90}$ in an equiibrium ratio. After centrifugation a sample of the solution was taken for measurement of the residual radioactivity. While the sorption experiment was taking place a sample was taken of the original solution, which served as a control. Measurement took place immediately after the samples were taken; they were then repeated during the next few days. To the test tube containing the soil and the radioactive solution, $CaCl_2$ was added until its concentration in the solution was 1.0 N. The soil was then mixed with the solution again, the mixture centrifuged, and a sample taken for measurements of the radioactivity; these were also carried out repeatedly during the next ten days and longer. In some experiments the solution was poured off after desorption and soil samples were taken for repeated measurements of the radioactivity during the next few days.

No large shifts of the ratio between Sr^{90} and Y^{90} were observed on adsorption of these radioisotopes by the soils; in a few experiments the direction of the shift was toward predominant absorption by the soils of the mother nuclide, but in others of the daughter nuclide.

More regular and more clearly pronounced shifts in the ratio between Sr^{90} and Y^{90} were noted in desorption from the soil: In one of the experiments measured with a counter, the radioactivity of the sample of solution obtained after the displacement by calcium chloride of the Sr^{90} sorbed on chernozem increased in two days from 7.4×10^3 to 10×10^3 counts per minute, and during the following seven days it rose further to 13.4×10^3 counts per minute.

In another experiment with the same soil, the radioactivity of a similar sample increased in six days from 4.98×10^3 to 11.5×10^3 counts per minute. In an experiment with krasnozem the radioactivity of the sample of the solution after displacement by calcium chloride of sorbed Sr^{90} increased in seven days from 1.26×10^3 to 2.22×10^3 counts per minute.

The residual radioactivity of the soil after the displacement from it of sorbed Sr^{90} changed in the opposite direction. In an experiment with chernozem, the radioactivity measured by a counter in this soil ten days later decreased from 33.7×10^3 to 8.5×10^3 counts per minute. These and similar data are evidence that when Sr^{90} sorbed by the soil is displaced into a solution of a neutral salt, the daughter nuclide Y^{90} is displaced far less completely than the mother nuclide Sr^{90}.

The fact that the mother nuclide Sr^{90} is easily displaced from the adsorbed state in soils as compared to the daughter nuclide Y^{90}, and that Y^{90} is taken up only with difficulty via the roots of plants results in the Y^{90} being left behind by Sr^{90} when the mixture $Sr^{90} + Y^{90}$ is absorbed by the roots of the plants. However, as the mother nuclide, strontium, accumulates in the plant tissues, reduction of the equilibrium ratio between Sr^{90} and Y^{90} takes place at the expense of the decomposition of Y^{90}. For this reason when repeated measurements are made of the radioactivity of samples taken from plants grown on soil containing Sr^{90} and Y^{90}, it is possible to confirm only a small tendency to change in the amount of radioactivity with time.

Considerably clearer results were obtained in our experiments in studying the translocation of the daughter nuclide, yttrium, and the maternal nuclide, strontium, in plants when Sr^{90} was introduced into the plant through the leaves. Here an unexpected fact was detected: there was a higher rate of translocation of the daughter nuclide yttrium in plant tissues.

In an experiment with the sunflower, 0.2 mc. of Sr^{90} was applied in solution to the second pair of leaves to develop—when plants were in the beginning formation of the anthodium. On the third day samples were taken for the measurement of radioactivity of those parts of the plants which had taken up Sr^{90} and Y^{90} from the treated leaves. After 11 days the radioactivity measured in the samples of leaves from the top of the sunflowers decreased to 14% of the activity measured the day the samples were taken; with further measurements it decreased to 7%. Similar observations were made in other experiments with foliar introduction of Sr^{90} and Y^{90} into the plant through individual leaves. The decline in radioactivity with repeated measurement of plant samples, especially those from young and growing tissues into which translocation of radioisotopes took place from the treated leaves, showed the relatively quicker uptake in them of the daughter nuclide, yttrium.

In experiments with grafted plants, radiostrontium was originally introduced through the roots of tomato plants which were then used as cions; the grafting took place on stocks not containing radioisotopes. After the cion had grown firm, samples were taken at definite intervals of different parts of the cion and stock and repeated measurements of the radioactivity of these samples were made. In one of such experiments after seven days the radioactivity measured in the leaves of the stock decreased to 30 to 40% of that measured immediately after the samples were taken. With this method, therefore, it was also possible to make an extremely clear observation of the relatively greater mobility in plants of traces of the daughter nuclide, yttrium, as compared to the mother nuclide, strontium, when there is no uptake through the roots and translocation takes place from one organ to another above the ground.

The principal cause of the difference in behavior in plants of traces of Sr^{90} and Y^{90} is the difference in the chemical groups to which they belong. In addition, consideration must be given to a specific circumstance caused by the radiochemical properties of such a system as $Sr^{90} + Y^{90}$.

When strontium and yttrium are taken up from an external medium containing Sr^{90} and Y^{90} in an equilibrium ratio and, passing through the roots, are translocated via the vascular system, a certain number of atoms of the daughter nuclide, yttrium, penetrate into the above-ground organs. These were formed in the external solution. But with time these atoms of yttrium decompose and in proportion to the uptake of Sr^{90} by the plant a new quantity of Y^{90} is formed in the tissues at the expense of the decomposition of the mother nuclide, strontium, which the plant took up. It can be assumed that the behavior of traces of Y^{90} which are continuously being formed by the decomposition of Sr^{90} in the plant tissues will be somewhat different from the behavior of atoms of yttrium taken up by the plant "in already prepared form" from the external medium. Localization of the source of the Y^{90} formed in the plant tissues will be related to the characteristics of the distribution in them of the mother nuclide, strontium, and consequently caused by the chemical properties of strontium and not by the chemical properties of yttrium. When they are formed from the decomposition of the mother nuclide Sr^{90}, the atoms of Y^{90} are excited at the expense of the energy emitted and this in turn is capable of influencing the eventual fate of that part of the Y^{90} atoms formed in the tissues when the mother nuclide, strontium, decomposes. It is possible that these factors are shown to some degree by increased mobility of the daughter nuclide, yttrium, in its translocation within the plant.

Conclusions

The processes of sorption and desorption in soils and the uptake by plants and distribution in them of traces of cesium, ruthenium, and zirconium were investigated in experiments using radioactive isotopes of these elements.

When plants are grown in water culture, they take up cesium and strontium at a higher rate and ruthenium and zirconium at a considerably lower rate. In this process the ruthenium and zirconium are retained preponderantly in the root system, while strontium and cesium pass to the above-ground organs, accumulating principally in the vegetative organs with relatively small quantities in the reproductive organs.

Investigations of the distribution of traces of the same elements when introduced into the plant through the leaves showed that cesium had the best ability to translocate from the treated leaves into other parts of the plant and to accumulate in the reproductive organs.

The processes of sorption and desorption of cesium and strontium in soils affected the uptake from the soil of radioactive isotopes of these elements by plants.

Although, in a water culture, cesium-137 and strontium-90 are members of the group of fission products taken up most rapidly by plants (as distinguished from elements such as zirconium and ruthenium which are taken up in relatively small quantities into the above-ground organs of plants), when a comparison is made of the uptake by plants of traces of the same elements from the soil, cesium is transferred to the group of relatively immobile elements, traces of which are taken up by plants from the soil in considerably smaller quantities than are traces of strontium.

Traces of strontium and cesium are sorbed by soils, in general, by ionic-exchange adsorption. However, while strontium retains practically all of its capacity to be displaced into the solution by reaction with neutral salts, traces of cesium are more tenaciously retained in the adsorbed state and so are not fully displaced into the solution by a neutral salt. Evidently some part of the traces of cesium adsorbed by the soil is fixed in non-exchangeable form, which may be one of the causes for the considerably smaller quantity of it taken up by plants from the soil as compared to the uptake of it from a water medium.

Traces of ruthenium are, as a rule, adsorbed at a lower rate by soils than are traces of strontium, cesium and zirconium, but, once having been sorbed by the soil, ruthenium, like zirconium, is not displaced from the adsorbed state by neutral salts. However, the importance of the soil sorption processes is shown to a lesser degree on the uptake of ruthenium and zirconium by plants than it is on that of cesium, since in water culture ruthenium and zirconium are distinguished by their low ability to translocate from the root system into the organs aboveground.

The fact that strontium is adsorbed by soils by means of ionic exchange and that it is easily desorbed account for the possibility of the relatively high rate of uptake of radioactive strontium from the soil into the plant. Applying fertilizers to the soil and liming acid soil both affect the uptake of strontium and cesium by plants. Liming strongly decreases the uptake of strontium. The application of potassium fertilizer decreases the uptake of cesium.

In the processes of sorption and desorption in soils of radioactive elements representing two genetically related radioactive nuclides (such as strontium-90 and yttrium-90), there is a disturbance of the equilibrium ratio between the mother and daughter isotopes. This disturbance of the equilibrium ratio between the mother strontium-90 and the daughter yttrium-90 is also observed when they are taken up by plants, and particularly seen when they are translocated from one organ of a plant to another. With foliar application of strontium-90 the daughter nuclide yttrium-90, formed in the leaf tissue, is translocated to young, growing tissue faster than the mother nuclide strontium. A similar phenomenon is confirmed in experiments with grafted plants where observations were made on translocation of $Sr^{90} + Y^{90}$ when traces of radiostrontium were introduced before grafting through the roots of one component of the grafted plant.

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SECRETION OF LABELLED PHOSPHORUS AND CALCIUM FROM THE ROOTS INTO THE SOIL IN ROOT-FED PLANTS

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Some interesting reports have been published in recent years that refine our conception of the processes by which nutrient elements are absorbed by plant roots. First, the overwhelming evidence led to a rejection of the Donnan equation as an explanation of principles governing the intake of substances by root cells. It later became evident that the very conception of the living cell as an equilibrium system is incorrect and that the absorption of ions by the cell is inseparably linked with metabolism and energy (3).

The nutrition of plants involves two opposing processes: the intake of nutrients into the roots and the secretion of these substances by the roots into the soil.

In experiments using water and sand culture Akhromeiko (1) noted the periodic excretion and absorption of substances by roots both in the course of a single day and during the growing period. Legumes and mustard plants differed from cereals by increased secretion of P_2O_5. Up to 35% of the P_2O_5 content of the whole plant was secreted.

Sokolov, using a radioactive isotope of phosphorus in a soil medium, demonstrated the possibility of secretion of phosphorus by the roots of plants and its absorption by the roots of other plants. However, it was not enough to assure the nutrition of other plants because the amount secreted was small (4).

On the basis of two experiments with isolated plants, Tikhonova (6) has concluded that roots do secrete potassium back into the nutrient medium, but that the amount released is small.

In a number of cases Kanivets (2) found enrichment of the rhizosphere by nutrient elements. He explained this by: 1) the intensity of biological activity in the rhizosphere and 2) the outflow of nutrients from plants and acceleration of the process of root mortality and decomposition during the period of maturation.

Sukhareva (5) showed that translocation of a radioactive isotope of calcium through the tissues of a plant may be accompanied by its secretion by the roots and transfer from one part of the container to another. In one experiment the amount of calcium excreted into the soil proved to be 20 times as large as the amount retained in the roots.

Kheifets (8) applied a solution of labelled phosphorus to the leaves of plants and found quick distribution throughout the entire plant and its secretion into the soil adjoining the roots. This secretion changed with time and varied with the phase of the plant's development and its species.

Procedure

We were interested in the amount of substances secreted into the soil with "normal" root feeding. Data are given below from greenhouse experiments in 1955 and 1956 where a study was made of the secretion of phosphorus by the root system. The root systems of plants were divided equally into two separate sections of soil from which the roots were simultaneously nourished. A NPK fertilizer was applied to one of the containers and NPK, plus radioactive phosphorus to the other. At the end of the experiment, the soil in the container to which the radioactive phosphorus had not been applied was analyzed and the presence of the tracer was always detected. This can be explained only by secretion.

Up to the present time in experiments with isolated soil nutrition we have not been able to calculate the amount of water lost from each side of the container. Incidentally, in experiments with soils differing widely in hydrologic properties and osmotic pressure of the soil solution, the expenditure of water by the plant from the different sides of the container was quite different. For these experiments we used a new type of container (7). It had a long rectangular shape; in the middle of the container, within a hollow partition dividing it into two equal sections, was fastened the shaft of the container.

When the plants were watered, the container was suspended by the shaft and became in effect the beam of a simple balance by virtue of which it was possible to calculate the expenditure of water from each half of the container and maintain a given moisture level in each section of soil. In all the experiments five corn plants were grown in each container, which held about 2 kg. of soil in the two sections. The experiments were replicated three times.

From both sections of all containers in this experiment, two soil samples were taken for the determination of radioactivity. In the experiments with labelled phosphorus radioactivity was determined in 2 g. of soil and 0.2 g. of plant material by means of a counter with aluminum walls.

In the experiments with two elements, samples of 1 g. of soil or the ashes of 2 g. of plant material were spread in a thin layer on the bottom of a standard glass beaker and the determination was carried out on an end-window counter, at first directly and then through a 0.16 mm. aluminum shield. It was determined that such a shield, by absorbing radiation, decreased the measured activity of Ca^{45} by 99% and that of P^{32} by 30%, which made it possible to calculate the amount of each of the two labelled elements in the sample. Compensation for self-absorption by the mass of the sample was calculated by two methods: by decrease in the measurable amount of activity of a radioactive substance when mixed with samples of soil or plant material; and by the curve of the change in radioactivity when the weight of the radioactive material was increased. The Ca^{45} content of the samples was also checked by the residual radioactivity of the samples after prolonged storage and almost complete decomposition of the P^{32} in these samples. The natural radioactivity of the soil was calculated by determining the background count under identical conditions of a sample of soil from a container in which radioactive substances had not been applied.

The 1955 experiments were done with a thick chernozem from the Kursk Central-Chernozem National Reservation. One hundred and seventy mg. of P_2O_5 were applied per kilogram of soil. In one section of each container the phosphate had a radioactive tracer consisting of 43 μc. of P^{32} per container at the beginning of the experiment. The plants were harvested at 19, 33 and 47 days following planting. When the plants were collected, soil samples were taken at all depths in the container with a drill; the roots were removed from the soil and, after drying, the quantity of labelled phosphorus was determined. Because of the plants there was a redistribution of the labelled phosphorus that had been applied with the fertilizer to one section of the soil (Table 1).

Results

Table 1 shows that the amount of labelled phosphorus detected in the "clean" soil (in the section of soil to which labelled phosphorus had not been applied) was not large (2 to 4 mg.), but was two to five times as great as the amount of labelled phosphorus in the roots of this soil. The amount of phosphorus secreted differed appreciably according to the time when the determination was made: under young plants it reached 4 mg. or a quarter of the content in the plants; but at later periods under the quickly-growing plants the quantity of labelled phosphorus again decreased, not exceeding 2.6 mg. or 1/10 to 1/15 of the content.

Treatments of the experiment differed according to the osmotic pressure of the soil solution (1, 5 and 9 atmospheres in the half of the container with labelled phosphorus). The amount of water taken into the plants from the soil fertilized with labeled phosphorus also varied widely, but this was not reflected in the secretion of labelled phosphorus in the other container.

We assumed that when enough phosphorus was supplied to the plant, the amount of phosphate secreted by the root would depend on the rate with which it was fixed by the soil. In the second experiment a comparison was made between the secretion of labelled phosphorus into chernozem and into krasnozem which actively fixes phosphates. The labelled phosphorus entered the plant through a part of the root system from chernozem where 170 mg. of P_2O_5 was applied with a label of 13 μc. at the time when the plants were planted in the container. In the other half of the container 170 mg. of phosphorus without a radioactive label was applied to krasnozem (first treatment) or chernozem (second treatment). The krasnozem received 0.9 grams per kilogram of $CaCO_3$.

The experiment did not confirm our assumption that, other conditions being equal in both experiments, the secretion of labelled phosphorus

TABLE 1

Distribution of labelled phosphorus in isolated sections of chernozem and corn plants (in milligrams of P_2O_5 per container)

Treatments	Time sample taken	In soil		In plants			Total found
		Without P^{32}	With P^{32}	Above-ground part	Roots from soil no. P^{32}	Roots from soil P^{32}	
For all treatments	Begin. of expt.	0[a]	170	0	0	0	—
First	19 days	3.7	158	12.2	0.7	2.0	176
	33 "	2.2	139	22.5	1.2	3.4	168
	47 "	2.6	121	26.6	2.5	6.3	158
Second	19 "	3.7	158	12.2	0.7	2.0	176
	33 "	not detd.	146	13.6	1.0	2.8	166
	47 "	2.6	131	24.2	2.1	5.0	164
Third	19 "	3.7	158	12.2	0.7	2.0	176
	33 "	1.9	153	16.3	1.0	2.6	175
	47 "	2.6	142	20.3	1.8	3.3	169
Index of accuracy of detn. of labelled phosphorus $\pm P_m$ %		30	5	6	9	6	—

[a] We do not show the data on absorption of phosphorus from another portion of the soil which had also been treated with 170 mg. of P_2O_5 without radioactive tracer, since it is not significant for the question under discussion. The table shows the averages for the treatments; each experiment was done in three containers, and two soil samples were taken for analysis from each container.

TABLE 2

Distribution of labelled phosphorus in isolated sections of different soils and in corn plants after 26 days growth of the corn (in milligrams of P_2O_5 per container)

Treatments	In soil		In plants			Total found
	Without P^{32}	P^{32}[a] applied	Above-ground part	Roots from soil no. P^{32}	Roots from soil P^{32}	
First	Krasnozem 1.3	Chernozem 90.9	44.3	2.5	5.0	144
Second	Chernozem 2.1	Chernozem 102.2	49.3	1.6	3.7	160
Standard deviation of the determination ± m	±0.14	±1.9	±1.34	±0.86	±0.62	—
Index of accuracy ±P, %	±8	±2	±3	±40	±14	

[a] To this part of the container 170 mg. of P_2O_5 and a labelled radioisotope was applied, while 170 mg. of P_2O_5 without a radioactive tracer was applied to the other part of the container. Data on total phosphorus uptake are not given here.

into krasnozem should take place at a higher rate (Table 2). In this experiment a somewhat greater secretion of phosphorus was detected in the chernozem than in the krasnozem. This is evidently related to a weakening of the development of the roots in the krasnozem (in which they weighed 2.2 g. as opposed to 2.8 g. in the chernozem).

The quantity of labelled phosphorus found in the soil was as large as in the preceding experiment, although the method of taking soil samples was different. All the soil in the container was carefully mixed, the roots were removed and a small amount of an average sample was taken. This sample was then freed of all rootlets visible under a magnifying glass, and not until then was it used for analysis.

The third experiment was carried out with sierozem and chernozem. We considered at the same time the translocation of two nutritive elements with radioactive tracers, phosphorus and calcium, applied together to the soil in one half of the container. The quantities of nutrients used were the same as in the preceding one; the radio-

TABLE 3

Distribution of labelled phosphorus and calcium in separate sections of the soil and in corn plants (P^{32} in milligrams of P_2O_5 and Ca^{45} in counts $\times 10^3$ per container)

Treatment	In soil		In plants			Total found
	Without radioisotopes	Fertilized with $P^{32} + Ca^{45}$	Above-ground part	Roots from soil without $P^{32} + Ca^{45}$	Roots from soil with $P^{32} + Ca^{45}$	
			Applied			
P^{32}	0	170	—	—	—	Not detd.
Ca^{45}	0	96	—	—	—	96
			Found			
Treatment 1	sierozem	chernozem	—	sierozem	chernozem	—
P^{32}	5.5	108	32.7	1.4	5.4	153
Ca^{45}	0.7	95.6	6.3	0.05	1.0	104
Treatment 2	chernozem	sierozem		chernozem	sierozem	
P^{32}	2.6	97	36.1	2.2	4.5	142
Ca^{45}	2.7	92.5	9.4	0.14	1.86	106
Treatment 3	sierozem	sierozem		sierozem	sierozem	
P^{32}	3.6	106	31.8	1.6	4.8	148
Ca^{45}	2.3	91.9	8.9	0.14	2.11	105
Treatment 4	chernozem	chernozem		chernozem	chernozem	
P^{32}	7.6	103	31.2	2.3	4.9	149
Ca^{45}	(0)	(71)	7.5	0.08	0.8	
Index of accuracy of expt. ±P, %						
for P^{32}	±32%	±6%	±5%	±15%	±8%	—
for Ca^{45}	±40%	±5%	±14%	±33%	±7%	—

active label at the beginning of the experiment was 13 μc. of P^{32} and 41.6 μc. of Ca^{45}. Growth of the plants in these treatments was equal and when harvested on the 56th day the weight of each did not differ by more than ±6%. The intake of labelled phosphorus by the plants from chernozem and sierozem also proceeded in like manner (Table 3).

The translocation of phosphorus took place easily, as shown by the comparative percentage content of P^{32} in the above-ground parts and roots in the soil with labelled fertilizer. In the soil to which the labeled phosphorus had not been applied the roots contained two to three times less labeled phosphorus than the other parts of the plant. This may be due, among other causes, to the flow from the roots to the soil (Table 4).

Regardless of this, the secretion of P^{32} was twice as great in those cases where the labelled phosphorus was taken up from chernozem (treatments 1 and 4), and less secretion if the sierozem was its source. Properties of the soil, in which secretion took place, seemed not to be reflected in the amount of secreted phosphorus.

Unlike phosphorus, the accumulation of labelled calcium in the plants differed noticeably: 50% more radioactive calcium was taken up from sierozem than from chernozem. Plants which had taken up labelled calcium from the sierozem had a greater amount of Ca^{45} in the above-ground parts and in the roots (treatments 2 and 3, Table 4).

The translocation of Ca^{45} took place at a lower rate than did the translocation of phosphorus. An especially small amount of calcium moved into the other portion of the roots located in the soil to which labelled fertilizer had not been applied. In these roots the Ca^{45} content per unit weight was 10 to 15 times smaller than in the rest of the plant. The secretion of Ca^{45} does not depend on the kind of soil it is secreted into, but on its concentration in the plant, that is, on its absorption by the plant or on the properties of the soil from which the element enters the plant.

The fact that phosphorus is taken up at the same rate from sierozem and from chernozem while calcium is taken up at sharply different rates is probably explained by the rate of exchange of these elements in the soil. The phosphorus compounds applied to the sierozem and

TABLE 4

Weight of plants and their radioactive isotope content

Treatment	Weight of plants in grams				Radioactivity of 2.0 g. sample in counts per minute for Ca^{45}			Radioactivity of 2.0 g. sample in counts per minute for P^{32}		
	Above-ground part	Roots in soil fertilized with P^{32} + Ca^{45}	Roots in soil without radio-isotopes	Total	Above-ground part	Roots from soil fertilized with P^{32} + Ca^{45}	Roots from soil without radio-isotopes	Above-ground part	Roots from soil fertilized with P^{32} + Ca^{45}	Roots from soil without radio-isotopes
Chernozem sierozem P^{32} Ca^{45}	40.3	7.2	5.4	52.9	330	290	20	61	56	20
Sierozem chernozem P^{32} Ca^{45}	39.3	5.6	5.1	50.0	500	617	61	69	60	32
Sierozem sierozem P^{32} Ca^{45}	37.0	6.4	5.8	49.1	497	696	49	65	56	21
Chernozem chernozem P^{32} Ca^{45}	42.3	6.5	6.5	55.4	372	253	27	55	57	27
Index of accuracy ± P, %	±4%	±8%	±12%	—	±14%	±6%	±35%	±8%	±11%	±27%

Note. The corresponding quantity of the nonradioactive isotopes of phosphorus and calcium was applied to the soil in the other half of the container.

chernozem did not change into slightly soluble state; the exchange of the applied phosphorus for the slightly soluble soil phosphates took place only to a slight degree. The uptake of labelled phosphorus during the experiment took place from the readily soluble compounds which were identical in these two soils.

The Ca^{45} applied to the soil labelled the different quantities of exchangeable calcium (the amount of exchangeable calcium and the adsorption capacity of chernozem is four to five times that of sierozem). For this reason the specific radioactivity of the exchangeable calcium in the sierozem should have been higher: for every gram of Ca there should have been a larger number of impulses from the labelled Ca^{45}. Under these conditions the uniform uptake of calcium by the plants should have been recorded differently—with less radioactivity for chernozem and more for sierozem. The total $CaCO_3$ content in sierozem was higher than in chernozem, but this calcium evidently did not take part in the isotopic exchange.

How reliable are the data obtained? Determinations of the radioactive elements in the aboveground parts of the plant and in soils "fertilized" by radioisotopes were made in all experiments with an accuracy of about 5%; in the roots the accuracy was less. When the amount of radioactivity applied to the soil was small, the radioactivity of the soil in the other half of the container which appeared as a result of secretion by the roots was of course small, and the accuracy of these determinations was less (±30 to 40%).

Conclusions

1. Secretion into the soil of radioactive phosphorus and calcium, which had been taken up by plants through isolated strands of roots from soil fertilized with labelled fertilizer, was found in all experiments.

2. The amount of labelled phosphorus secreted from the roots in experiments with young corn plants was 2 to 7 mg. of P_2O_5 (from 4 to 25% of the content of labeled phosphorus in the plants). The total amount of phosphorus secreted into the soil exceeded its content in the roots, but the radioactivity per gram of the roots was 20 to 30 times as high as the radioactivity per gram of soil.

3. Phosphorus secretion from roots to soil was influenced by its content in the plant and the age of the plant as well as by certain soil conditions determining the uptake of this element.

Increased osmotic pressure of the soil solution, which sharply decreased the uptake of water from the soil, was reflected only weakly on the uptake of phosphates and caused no change at all in the secretion of P_2O_5 into the soil. Approximately equal quantities of labelled phosphorus were taken up by plants from chernozem and sierozem. The secretion of phosphorus taken up from chernozem proved to be somewhat greater than that taken up from sierozem.

4. The amount of phosphorus secreted from the roots did not depend on the properties of the soil into which the secretion took place.

5. The secretion of the labelled calcium of the

roots, like that of phosphorus, did not depend on the properties of the soil into which it was secreted, but it did depend on the amount of this element in the plant and on the properties of the soil from which the labelled calcium was taken up.

6. The uptake of Ca^{45} by plants and its accumulation in them depended to a greater degree than did phosphorus on the properties of the soil: more Ca^{45} was taken up from sierozem than from chernozem. Its translocation from one part of the root system to another took place less extensively than did that of phosphorus.

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GLEY-PODZOLIC SOILS

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Soil cover research in the upper Vychegda river basin was organized in 1947 and 1948 by the Soil Section, Komi Branch, of the Academy of Sciences, USSR. Administratively this area constitutes the northern half of the Pomozdinskii district of the Komi Autonomous Soviet Socialist Republic. Field examinations were made by I. V. Zaboyeva and D. M. Rubtsov, and work was carried out under the direction of Professor E. N. Ivanova.

This region is in the moderate-to-cold climate zone; the mean annual temperature is −0.2° and the growing season is about 130 days (1). Hot weather, when it occurs, is not persistent and there are often frosts in June. The mean annual precipitation is 500 to 520 mm., of which 300 mm. falls in warm weather. Relative humidity of the air is usually above 60% and soil water balance is always positive.

The relief is typically eroded. In the northern and eastern area are the basins of the upper Kenzhan and Lesnaya Chir rivers, the middle reaches of the Cher-Vychegodskaya, and the upper part of the Vychegda and the Vychegdo-Pechorskii watershed. These have the greatest elevation (absolute altitude, 200 to 300 meters). The slanting surface is full of hillocks which are dissected by a system of small streams and hollows. Only the central parts of the broadest watersheds have not been eroded. These have flat plains without noticeable fluctuations in elevation. The drainage belt of the rivers is 2 to 3 km. wide. The remaining surface of the watersheds is bog. In the entire southern part of the area the maximum altitude of the hillocks is 200 meters. Gradual surface depression occurs toward the south.

This is the area of the eastern terminal spurs of the Southern Timan Range. Native rocks in the northern part are Carboniferous and Devonian limestones. The entire southern part is composed of Permian deposits, represented by various limestones with local outcroppings of gypsum (13). The parent material consists solely of Quaternary deposits of glacial origin. In the higher northern part silty clay loams are distributed. The southern part is composed of heterogeneous alluviums—sands, sandy loams and various groups with two constituents.

The silty clay loams (both covering and loessial types), underlain by morainal clay loam, have a characteristic (pale) yellow-brown color. On the watersheds it is seldom thicker than 1.5 to 2 m. The sandy clay loams contain no coarse deposits but have up to 50% of particles larger than silt (the fraction 0.05 to 0.01 mm.). They have a fairly high adsorption capacity: total exchangeable cations amount to 17 to 26 me. per 100 g. of soil.

The explored area is in the central part of the taiga where spruce forests predominate with an admixture of fir, cedar, or, less often, deciduous trees. Spruce is exceeded by pine only on deep sands and on strongly waterlogged tracts of upland bogs where the peat is thicker than 60 cm.

The most complete investigations were made of gley-podzolic soils, which are not typical of the central taiga. These soils were first characterized by Ivanova (10, 11) from the examinations along the Pechora railroad (3, 4, 14). Gley-podzolic soils of the northern taiga and the forest-tundra have the following characteristics: 1) gleyed upper horizons—chiefly the podzolic, A_2; 2) humus washed along the entire profile, and the absence of a humic-illuvial horizon; 3) weaker development of podzolization in comparison with the podzolic soils developing further south; and, finally, 4) weak accumulation of plant residues, related to the failure of the turf horizon (A_0) to exceed 5 cm. in thickness. These soils were encountered on fine-textured silted clay loams in well-drained localities.

In the northern part of the central taiga subzone, gley-podzolic soils are less gleyed and have a thicker underlying deep humus horizon (7 to 10 cm.). They develop in belts along rivers, on slopes of watershed hills, and on narrow interfluves.

To characterize gley-podzolic soils we will give a description of section 185-3 (taken from a point at 62° 34′ N., 55° 25′ E.):

Located on a southwestern slope (about 2°) leading to a small stream; elevation 230 m.;

microrelief formed from deadwood of different ages overgrown with moss, flattened into mounds 10 to 15 cm. high. Forest: Site Class III, spruce with individual birch and cedar; undergrowth of fir, particularly in the form of "fir flooring." *Hypnum* predominates on the immediate soil surface. *Polytrichum* is scattered in small spots and diffused; of the bushy plants there are blueberries *Vaccinium vitis idaea* L. and *V. myrtillus* L., and linnaea and cowwheat as individuals.[1]

A_0, 0 to 8 cm. Poorly decomposed moist dark-brown litter.

A_0^1, 8 to 9 cm. Brownish-gray layer representing the lower part of the litter mixed with mineral particles; pierced by the rhizoids of mosses; not seen in all sections.

A_2g, 9 to 15 cm. Medium silty clay loam, dark bluish-white with diffuse rusty or corroded spots; structure indistinctly expressed, but flaky. Many orstein concretions.

B_1, 15 to 41 cm. Medium silty clay loam, brown; at the margin adjoining A_2g, a discontinuous rusty-brown layer. In the upper part of the horizon dark bluish-brown spots; orstein concretions; structure lumpy and flaky; porous; transition to following horizon gradual.

B_2, 41 to 70 cm. Fine silty clay loam, reddish-brown with a clearly nutty structure; porous, dense; transition to following horizon gradual.

BC, 70 to 110 cm. Fine silty clay loam, reddish-brown, dense; structure definite, large-nutty (angular-lumpy); indistinct sprinkling of silica; porous; transition to following horizon gradual.

C, from 110 cm. Fine silty clay loam, brown, less dense, porous, very cohesive fused-flaky structure; (slight admixture); some rusty-brown spots; depth of section 155 cm.

The texture of the soils investigated is shown in Table 1. The figures show that these soils have developed on a homogeneous parent material—fine silty clay loam. In the process of development from a podzolic horizon about 40 to 50% of the clay particles have been decomposed. There is no horizon in which clay accumulates down to the examined depth of 150 cm.

For the purpose of mineralogical analysis, the 0.1 to 0.01 mm. fraction was divided into other fractions of differing specific gravity. Its main portion is composed of minerals with a specific gravity of 2.44 to 2.75 (Table 2).

The preponderant minerals in the profile are quartz and feldspars, with small quantities of micas and chlorite. The heavy fraction includes ore minerals, zircon, rutile, garnet, tourmaline, sphene, disthene, anthophyllite, anatase, brookite, epidote, pyroxene, and green hornblende. The heavy fraction gradually increases with depth. This suggests that the silty clay loams were formed by gravitational sedimentation from the upper layer of morainic alluvium, rather than by the weathering process (6).

The clay fractions were subjected to x-ray and thermal analyses (Table 3 and Fig. 1). (The analyses were carried out by E. A. Shurigina of the Mineralogical Laboratory, V. V. Dokuchayev Soil Institute, Academy of Sciences, USSR.)

Table 3 shows that montmorillonite composition is characteristic for the mineral part of the adsorption complex. This is confirmed by the molecular ratio of SiO_2 to Al_2O_3, which is close to 4. The surfaces of the mineral particles are covered by films of amorphous compounds which decrease their exchange property (18), explaining the negligible exchange capacity of the colloids.

The thermal analysis of the same clay fractions agrees fully with the data from the x-ray analysis. The figure shows the thermal curves

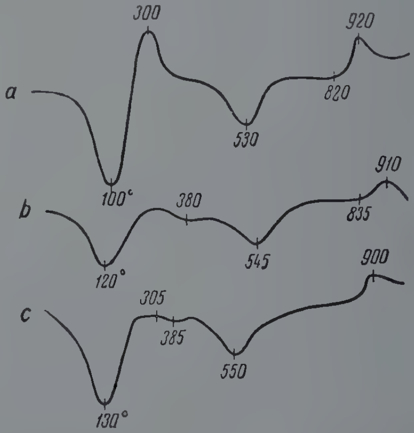

Fig. 1. Thermal curves of the clay fraction of gley-podzolic soil (section 185): a. horizon A_2g (depth, 10 to 15 cm.); b. horizon B (35 to 40 cm.); c. horizon C (150 to 155 cm.).

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[1] An extremely small proportion of grassy plants on the soil surface is a characteristic peculiarity of the central taiga. Soil formation takes place here in an almost complete absence of peat formation.

TABLE 1

Texture of gley-podzolic soils

(Analysis by V. A. Popov)

Section No.	Horizon	Depth of sample, cm.	Coarse particles, %	Diameter of particles in millimeters						Total particles <0.01	Eluviation or accumulation of fraction <0.001 mm. as % of it in parent material
				1.0–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001		
185	A_2g	10–15	0	3	59		11	9	18	38	−38
	B_1	16–26	0	3	58		7	9	23	39	−21
	B_1	35–40	0	1	57		9	8	25	42	−14
	B_2	50–60	0	1	53		9	9	28	46	−4
	C	150–155	0	0	53		8	10	29	47	0
199[a]	A_2g	6–11	0	1	9	58	6	9	17	32	−49
	B_1	12–20	0	1	7	56	7	7	22	36	−34
	B_2	35–45	0	0	8	56	6	8	22	36	−34
	C	140–150	0	0	7	49	5	6	33	44	0

[a] The section was located in a belt along a river. The forest was site class III to IV spruce. In the immediate soil cover there was a preponderance of *Hypnum* with a diffuse admixture of *Polytrichum* and individual cowwheat, forest horsetail, and blueberry bushes.

for the fraction <0.001 mm. The thermal curves were interpreted by E. A. Shurigina. Beidellite is preponderant in the clay fraction of the podzolic horizon, with peaks at 100°, 530°, 825° and 925° C. The large amount of adsorbed water is related to the hydrophilic property of the material examined. In addition to beidellite in the fraction <0.001-mm., there are amorphous hydrophilic admixtures: humus (exothermic peak at 300°); amorphous silicic acid (peak at 100°); and amorphous iron hydroxide (peaks at 100° and 300°).

In the illuvial horizon (depth 35 to 40 cm.) ferribeidellite is preponderant (peaks at 120°, 545°, 835°, 910°). There is also goethite (peak at 380°), and a smaller content of amorphous hydrophilic admixtures than in horizon A_2g. In the parent material at 150 to 155 cm. ferribeidellite predominates, with peaks at 130°, 550° and 900°. Iron oxide minerals (peaks at 305° and 385°) and a considerable amount of amorphous admixtures are present.

Chemical analyses of gley-podzolic soils (Table 4) show their high acidity and extended acidity profile. Maximum acidity is in the top layer and its decrease downward is evidence that fallen plant material is the original source of the

TABLE 2

Results of the gravitational analysis of the fraction 0.1 to 0.01 mm. of gley-podzolic soil

Horizon	Depth of sample, cm.	Content of fractions of different Sp. Gr. as % of wt. of fraction			
		0.1–0.01 mm.	<2.44	2.44–2.75	>2.75
A_2g	10–15	59	2.25	90.64	4.20
B	35–40	56	0.54	93.80	5.60
C	150–155	52	1.85	91.70	6.17

TABLE 3

Result of an investigation of a gley-strongly-podzolic soil

Horizon	Depth of sample, cm.	Content of fraction < 0.001 mm., %	Hygroscopic moisture of fraction <0.001 mm., %	Loss on ignition, %		Mineral content, %				Approximate content of amorphous substances, %[a]	Adsorbed cations (Gedroits method) in me./100 g. soil			Molecular ratio $SiO_2:Al_2O_3$
				Humus (acc. to Tyurin)	Chemically bound water	Montmorillonite group	Micas	Hydromica (Kaolinite)	Quartz		Ca	Mg	Ca + Mg	
A_2g	10–15	18	7.43	10.57	7.25	~30	10–15	~10	3–4	40–45	3.07	0.71	3.77	4.3
B	35–40	25	7.25	5.15	8.65	30–40	10–15	10	5	30–35	2.43	4.09	6.52	4.0
C	150–155	29	6.60	1.33	9.37	20–30	10–15	10	2–3	50	9.43	4.66	14.09	3.9

[a] Their presence was shown by a slight background on the x-ray.

TABLE 4

Chemical analysis of gley-podzolic soil from central taiga

Horizon	Depth of sample, cm.	Hygroscopic water, %	Loss on ignition, %	Humus, % (acc. to Tyurin)	pH		Hydrolytic acidity K = 1.75	Exchangeable acidity (acc. to Sokolov)			Exchangeable cations (acc. to Gedroits)				Mobile Fe_2O_3 and P_2O_5 in mg. per 100 g. of soil (Kirsanov's meth.)		Eluviation or accumulation of exchangeable cations (Ca + Mg), %	Eluviation or accumulation of exchangeable cations (Ca + Mg), %	Unsaturation, % (Gedroits meth.)
					Aqueous	Saline		Total	H	Al	Ca	Mg	H	Total Ca + Mg + H	Fe_2O_3	P_2O_5			
							In milliequivalents per 100 grams of soil												
A_0	0–8	14.3	87.5	—	4.1	3.4	91.0	7.80	3.54	4.26	17.0	8.6	20.0	45.6	9	4	(+146)	(+180)	44
A^1_0	8–9	9.3	29.3	—	3.9	3.6	48.0	—	—	—	3.9	1.6	10.0	15.5	81	4	−57	−5	65
A_2g	9–15	3.8	5.8	2.7	4.4	3.1	19.3	9.13	0.35	8.75	1.1	0.6	7.0	7.7	46	1	−84	−53	91
B_1	16–26	4.3	4.1	1.6	4.4	3.5	19.3	9.04	0.15	8.89	1.4	1.0	8.6	11.0	39	1	−77	−30	78
B_1	30–40	3.8	3.4	1.3	5.0	3.8	5.7	—	—	—	1.4	1.0	7.1	9.5	19	1	−77	−42	75
B_2	50–60	4.3	5.8	1.0	4.8	3.8	16.4	9.16	0.10	9.06	1.3	1.2	—	11.7[a]	25	5	−76	−28	79[a]
BC	80–90	5.3	3.0	0.5	5.0	3.7	16.7	9.91	0.14	9.77	3.3	2.2	—	15.3	13	9	−46	−6	65
C	150–155	4.9	3.3	0.4	5.2	3.7	11.4	5.91	0.11	5.80	6.7	3.7	—	16.3	23	11	0	0	36

[a] For B_2, BC and C the exchangeable acidity was determined by Sokolov's method.

acidity. The exchangeable cations are almost completely leached from the upper horizons. It is characteristic that loss of available cations is observed to a considerable depth. But even with this, the total adsorptive capacity (Ca + Mg + H) remains fairly high in the profile. The loss of exchangeable cations amounts to 53% in comparison with the parent material. Thus, eluviation of the adsorbed cations is not accompanied by such a high rate of mineral decomposition of the absorbing complex. As Zavalishin (8) correctly notes, in these soils the total amount of cations in the upper horizons may be increased on account of a considerable content of illuvial organic matter which is at the same time a source of exchangeable acidity. Nevertheless, we must not emphasize that the degree of clay fraction decomposition, and consequently of podzolization, remains relatively low. In the presence of high acidity this is explained by the fact that in gley-podzolic soils acidity is caused chiefly by aluminum.

The percentage of exchangeable cations in the litter is considerably higher than in the mineral horizons and in the parent material. However, if a calculation is made of the amount of exchangeable cations associated with a definite volume (800 cm.^{3}), a different ratio is obtained (Table 5). The very low relative content of exchangeable cations in the top layer shows the low ash content of fallen plant material and its slow decomposition. It is characteristic that gley-podzolic soils accumulate mobile iron compounds in the upper horizons: up to 46 mg. of iron per 100 g. of soil is contained in the A_2g horizon.

Research by Dosmanova (7) and by Verigina, Zavalishin and Maksimyuk (5) showed that gleying is accompanied by the mobilization of all mobile forms of iron. In the gley horizons of the gley-podzolic soils we are describing, there is a general background of eluviation of iron, but a relative accumulation of the most mobile forms of iron is observed in comparison with parent material.

Total composition of the soil differs considerably from that of the clay fraction (Table 6). The content of silicic acid is much higher in the soil and gradually decreases with depth. The content of sesquioxides, on the other hand, is considerably greater in the clay fraction.

The content of sesquioxides (chiefly of iron) is quite low in the podzolic horizon. Research by Ponomareva (15) has shown that in podzolic soils the mobile zone of aluminum is about 20 times smaller than the mobile zone of iron.

TABLE 5

Contents of exchangeable cations per unit volume of soil

Section No.	Horizon	Depth of sample, cm.	Volume weight	Content of exchangeable cations in me. per 800 cm^3	Eluviation or accumulation of exchangeable cations in % as compared to parent material
185	A_0	0–8	0.06	12.3	−90[a]
	A_2g	9–15	0.8	10.9	−91
	C	150–155	1.5	124.8	0
186	A_0	0–8	0.06	16.3	−92
	A_2g	9–14	0.8	15.4	−92.5
	C	150–155	1.5	204.0	0

[a] In determining the degree of eluviation or accumulation of exchangeable cations we made only a comparison between the litter and the original material.

It is characteristic that the clay fraction has a very low calcium content but at the same time contains a relatively large quantity of magnesium. This is explained by the x-ray analysis of the fraction, according to which up to 40% of its content consists of montmorillonite minerals containing magnesium. The large percentage of chemically bound water is evidently caused by the presence of considerable quantities of hydrated sesquioxides.

Molecular ratios of SiO_2 to R_2O_3 are evidence of the eluviation of sesquioxides. Those values of the eluvial-accumulative coefficients are characteristics showing that the profile of gley-strongly-podzolic soil belongs to the group of "evenly eluviated" profiles (17) which do not show an illuvial horizon. The ratio $SiO_2:Fe_2O_3$ in the clay fraction is smallest in horizon B, showing its relative accumulation of iron compounds represented, according to the thermal analysis, by ferribeidellite and goethite.

Data from the analysis of the composition by groups and fractions of humus (Table 7) show the high mobility of humic substances and the sharp preponderance of fulvic acids in the soil makeup. In horizon A_2g, even in the decalcinate, carbon amounted to 8% of the gross and in horizon B to 13%. The decalcinate was completely colorless.

In soils with an extremely high relative acidity, Zavalishin has suggested that treatment by sodium sulfate solution is, essentially, treatment by a sulfuric acid solution. For this reason such

TABLE 6

Results of a complete analysis of a gley-podzolic soil (in % of ignited soil)—Section 185

Horizon	Depth of sample, cm.	Hygroscopic water, %	Loss on ignition, %		SiO_2	Fe_2O_3	Al_2O_3	R_2O_3	CaO	MgO	Total	Molecular ratios		
			Humus (acc. to Tyurin)	Chemically bound water								SiO_2: R_2O_3	SiO_2: Fe_2O_3	SiO_2: Al_2O_3
Soil														
A_2g	10–15	2.4	4.9		80.27	3.61	10.50	14.11	0.77	0.69	95.84	10.9	59.8	13.3
B	35–40	2.5	4.5		76.33	5.76	12.55	18.31	0.82	1.06	96.52	8.2	35.3	11.1
C	150–155	2.8	4.3		73.78	5.64	14.84	20.48	0.86	1.48	96.60	6.8	34.8	8.4
Clay fraction (<0.001 mm.)														
A_2g	10–15	7.43	10.57	7.25	58.00	8.00	25.52	33.52	0.48	2.27	94.27	3.2	19.0	4.3
B	35–40	7.25	5.15	8.65	53.87	15.56	22.76	38.32	0.34	2.98	95.51	2.8	9.0	4.0
C	150–155	6.60	1.33	9.37	54.99	12.99	23.86	36.85	0.63	2.99	95.46	2.9	11.0	3.9

TABLE 7

Composition by groups and fractions of the humus of gley-podzolic soil as percent of total carbon (Section 185)

Horizon	Depth of sample, cm.	Soluble in 1.0 N Na_2SO_4	Humic acids				Fulvic acids					Hydrolyzed in 1.0 & 0.5 N H_2SO_4	Insoluble residue (humin)	Bitumens	Total C in soil	$\frac{\text{Humic acids}}{\text{Fulvic acids}}$
			1	2	3	Total	0	1	2	3	Total					
A_2g	10–15	8	10	0	6	16	4	14	10	5	33	14	21	12	1.61	0.5
B	25–30	13	5	0	5	10	2	22	21	5	50	9	19	13	0.87	0.2

treatment may dissolve not only the water-soluble organic matter but also the acid-soluble—the so-called "zero fraction" of fulvic acids (according to I. V. Tyurin). It is obviously just this fraction of the organic matter which accumulates in an illuvial horizon.

A unique characteristic of the humus of gley-podzolic soil is also the complete absence of humic acids of the second group. Consequently there are no compounds of humic acid with calcium. Humic acid is represented in the free form, isolated by a solution of 0.1 N NaOH without decalcination (first group), and in the form of humic acids bound to iron and aluminum in the form of complex compounds isolated only by boiling with 0.5 N and 1.0 N H_2SO_4 in turn.

The situation is different with fulvic acids. The carbon of the total fulvic acids amounts to 33%. There are four fractions in all. The first, which is predominant, contains free forms of fulvic acids and some fulvic acids bound to sesquioxides. A second fraction is that which is most resistant to hydrolysis. According to Tyurin's outline, we must assume that this form of fulvic acid is bound to calcium. However, there is only about 1 me. of absorbed calcium in this horizon, while the absorbed aluminum amounts to about 10 me. Under these conditions, as Zavalishin notes, the operation of decalcination is converted into the displacement of absorbed aluminum. For this reason the increase in solubility of fulvic acids following this treatment is naturally associated with the removal of a certain excess of mobile aluminum, and as a result it is more correct to determine these soil compounds as bound to aluminum and not to calcium.

There is only about half as much total humus in the illuvial horizon as there is in horizon A_2g. Here there is an even greater preponderance of easily mobile forms of humus: the total of all groups of fulvic acids amounts to 50%. The increase in fulvic acids occurs mostly in the form of organomineral compounds of sesquioxides.

The composition study of organic matter in soils of the Komi ASSR were carried out by

Baranovskaya (2), who established the distinctive characteristics of the humus of northern soils.

As noted before, Ivanova (10, 11) considered the weakening of podzol formation in the gley-podzolic soils of the northern tundra and forest-tundra. On the basis of all the analyses we came to the same conclusion:

This weakening of podzol formation toward the north, primarily on finer parent material, is noted by a number of investigators. Zavalishin (8) associates this phenomenon with peculiarities of mossy vegetation as a less active factor than grassy vegetation. Remezov's paper (16) shows that the vegetation, by assimilating different elements from the soil increases the mobility of these elements and intensifies their eluviation from the soil. Since the plant cover of the northern and central taiga withdraws considerably less material from the soil than does the vegetation of the southern taiga, the result is that the rate of podzol formation in the northern and central taiga should be lower. Further, in the northern and central taiga the depth of podzol formation is extremely limited because of the absence of vegetation with deep and abundant root systems.

In the paper which Rode (17) devoted to the study of podzol formation principally in the southern taiga (in peat-podzolic soils) a series of eluvial-accumulative coefficients is cited on the basis of applying a large number of complete analyses. The series is assembled in order of decreasing eluviation of individual oxides from the podzolic horizon:

$$\frac{\text{MgO}}{-0.697} > \frac{\text{Fe}_2\text{O}_3}{-0.667} > \frac{\text{CaO}}{-0.562} > \frac{\text{Al}_2\text{O}_3}{-0.465}.$$

For the podzolic horizon investigated by us in gley-podzolic soil this order changed little:

$$\frac{\text{MgO}}{-0.592} > \frac{\text{Fe}_2\text{O}_3}{-0.412} > \frac{\text{Al}_2\text{O}_3}{-0.350} > \frac{\text{CaO}}{-0.177}.$$

Comparing the two series, the basic difference is in the absolute values of the eluvial-accumulative coefficients: the eluviation of all oxides from the podzolic horizon of gley-podzolic soil is considerably less than from the same horizon of the podzolic soil of the southern taiga. We came to the same conclusions on the basis of a comparison of the eluviation of the mobile part of the absorbing complex of gley-podzolic and other subtypes of podzolic soils.

In gley-podzolic soil, eluviation from horizon A_2g of $Ca + Mg = -84\%$; that of $Ca + Mg + H = -53\%$. The corresponding values for mountain-forest nonpodzolized soils are -18% and $+1\%$ (12) and for podzol of the southern taiga -91% and -83% (9). In gley-podzolic soils, regardless of increased acidity, the absorbing complex is more stable than in the podzols of the peat-podzolic subzone.

This stability of the absorbing complex results to some extent from the protective action of aluminum and iron.

From the material presented above we conclude that in gley-podzolic soils the podzol-forming process is quantitatively and qualitatively different from that of areas further south. Toward the north it is not a simple weakening of the degree of podzolization but a qualitative change in it. This shows the occurrence of stages of podzol formation in different subzones of podzolic soils.

Conclusions

1. As a result of this research it has been established that gley-podzolic soils, known as the zonal soils of the forest tundra and northern taiga, develop under definite conditions in the northern half of the central taiga as well. They are formed on elevated portions of the relief (at altitudes above 200 m. above sea level) on fine clay loams. This represents a shift of the soil subzones toward the south, that is, the soil is becoming adapted to the north.

2. The most characteristic genetic peculiarity of gley-podzolic soils is the gleying of the upper part of the profile, chiefly of the podzolic horizon. In this connection the accumulation of mobile forms of iron compounds takes place against a background of its general eluviation.

3. In gley-podzolic soils as in typical podzolic soils, there is an absence of a humus-accumulative horizon A_1 (the formation of podzol develops in the almost complete absence of a peat-forming process). The principal source of soil humus is the litter of mosses. Because of the low ash content of this litter, the exchange acidity of the upper horizons usually exceeds the total of exchangeable cations in the same horizons. In this the exchange acidity is caused in the mineral horizons almost exclusively by aluminum (or

iron), which is one of the genetic peculiarities of these soils.

Under the litter, gley-podzolic soils sometimes have an indistinct pre-humified layer of 1 to 2 cm. This is not accumulative, but rather an illuvial horizon formed by humus which has penetrated this far from the surface litter.

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PORE FORMATION IN TAKYR CRUST

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Takyrs are unique typical soil formations of the Central Asia desert plains. As a result of the unique climatic, geological and geomorphological characteristics of the plains of Turkmenistan, takyrs are located everywhere there: on the Kopet-Dag piedmont plain, on the deltas of the Murgab, Tedzhen, Atrek and Amu-Dar'ya rivers, in the Prikugitanskii region, and on the lowlands of southeastern Kara-Kum.

In spite of the great importance of this soil process in Central Asia, its mechanism and naure will probably remain in dispute until soil scientists choose direct experiment rather than “logical inference”.

In the present article we will not touch on the entire series of complex physico-chemical processes taking place in the takyr but will concentrate on the phenomenon of the formation of cellular “dry-bread” type of porosity of the crust. Dimo (7) was one of the first to consider the unique porosity of takyr crusts. He explained that they occurred as a result of air compression at the moment when precipitation penetrates into the soil. The author assigns a subordinate role to carbon dioxide of biological origin. E. N. Ivanova upheld this opinion, as Gorbunov and Labenets have done more recently. These authors assume that “the formation of porosity in the takyr crust is caused by the exit of trapped air when rainwater and snowmelt penetrate the soil. At the surface of the takyr air is partially retained by the dispersed layer of the soil and by the solid algal film” (p. 691). Rozanov (9) also considers the cause of porosity to be the displacement by moisture of the air of the soil, emphasizing the unique structure caused by the enormous pressure developing in the crust during the contraction of drying.

More recently Bazilevich, Gollerbakh and Rodin (1, 2) have put forth an original but, unfortunately, inadequately basic hypothesis for the formation of the cellularity of takyr crusts. In their opinion the pores represent cemented calcium carbonate cells containing bubbles of oxygen given off by algae in the process of photosynthesis. The bubbles of oxygen retained by the algal film “gradually are buried by suspended matter and preserved. The repetitive nature of this process leads to the growth of layers of buried bubbles and the gradual rise of a stable spongy-porous crust” (2, p. 340). The lack of experimental data led us to study this phenomenon in greater detail. In the summer of 1956, during a preliminary exploration of takyr areas, it was discovered that the surface of one of the takyr-studded solonchaks near the railroad station of Dzhu-Dzhu-Klu (in the Murgab-Tedzhen interfluve, Turkmen SSR) was covered continuously with small round openings which on closer inspection proved to be cellular pores. The absence on the surface of visible traces of the growth of either higher or lower plant organisms made the surface pores evident. They were usually masked by the residues of algal film or by colonies of lichens. The pores were often transected by the later occurrence of cracks, on the walls of which spherical depressions were distinctly seen. The external openings were not characteristic of the actual size of the pores, since below the surface the cavity of the pores broadened out, taking on the shape of a ball. Around the opening a circular ridge was noted, giving each pore the appearance of a miniature “crater”. The distribution of the openings on the takyr surface was uneven, the distance between individual pores varying from 1 to 10 cm. The diameter of the pores varied from 0.5 to 4 mm. The crust was dissected by thin cracks 1 to 2 mm. wide with sharp edges, while the individual polygons formed by them had not yet taken on the permanent characteristics of relatively young takyrs. The polygons showed microdepressions in which it was sometimes possible to notice thin filaments of the separate higher thalli of algae.

In the profile of a takyr (section 15) there was separated a stable, cemented, clayey crust 6 cm. thick, dissected by vertical cracks and pierced all over by large pores. In its upper part (0 to 0.5 cm.) there were signs of beginning solodization (some whitening and coarsening of the texture). To a depth of 12 cm. below the

TABLE 1

Composition of the water extract of takyr solonchak (Sect. 15, July 6, 1956, Murgab-Tedzhen interfluve 2 km. south of Dzhu-Dzhu-Klu railroad station. Analysis by V. S. Burdigin.)

Depth of sample, cm.	Hygroscopic moisture, %	As percent of oven-dry soil						
		Solid residue	Alkalinity		Cl^-	$SO_4^=$	Ca^{++}	Mg^{++}
			$CO_3^=$	Total in HCO_3^-				
0–0.5	1.78	1.17	none	0.02	0.52	0.06	0.10	0.02
0.5–6	1.94	1.23	“	0.03	0.62	0.09	0.06	0.03
6–12	1.33	1.21	“	0.03	0.57	0.07	0.04	0.01
12–27	3.57	2.91	“	0.03	0.95	0.60	0.21	0.06
27–80	3.55	2.15	“	0.03	0.83	0.46	0.12	0.05
80–10	1.85	0.48	“	0.03	0.23	0.06	0.02	0.02

crust there was a friable flaky-lamellar clay horizon. Below was a dense brownish clay saturated with salts having nodules of gypsum.

The analysis of a water extract (see Table 1) shows the solonchak salinization of the soil in which the salt content is very high (1.17%) even from the surface. It is natural that in such a soil the activity of biological factors would be considerably inhibited. However, we seeded soil samples from the upper and lower layers of the crust in Bristol solution to develop the species composition of the algae, regardless of the high salinity. This showed the presence of the following species:

Chlorella vulgaris Beyer	many
Pleurococcus vulgaris Menegh	quite a few
Chlorococcum sp.	many
Microcoleus vaginatus (Vauch.) Gom.	individual threads
Oscillatoria sp.	“ “
Phormidium sp.	“ “
Hantzschia amphioxys (Ehr.) Grun.	“ “
Navicula sp.	many
Achnanthes sp.	“

We began the study of the cellular structure formation from the moment the atmospheric precipitation fell on it. The dry, saline takyr crust with intact structure was placed in a crystallizing dish and sprayed with distilled water from a sprinkler. In this process the abundant effervescence of bubbles of air was observed, while the crust slaked before the observer's eyes and settled on the bottom of the crystallizing dish in a layer of separate particles. Each bubble of air was like a microscopic charge of explosive, destroying the crust from within. Gorbunov and Bekarevich state that when the air is displaced by water, destruction of the structure and pulverization of the soil take place. Pulverization increases more rapidly as temperature increases and moistening takes place.

According to our observations, in addition to the factors stated, the ratio between volumes of the solid phase of the soil of the pores plays a large part in the absence of a water-stable structure. The greater the porosity of the crust, the more air will be trapped in the pores and the stronger its destructive activity will be at the moment when it is quickly flooded by water. The same crust, retaining its salt composition and deprived only of its pores (as will be discussed later) was broken down with considerably greater difficulty by the action of water.

The abundant showers which occur in May and June of some years doubtless exert a strong slaking action on the structure of takyr crusts. For this reason, in spite of the opinion of Bazilevich et al. (2), the preservation and accumulation of porosity over a number of years is scarcely possible.

A protective action of algal film (6) preventing the release of entrapped air may occur, but only at those times of the year when it is fairly well developed (in fall or winter and in early spring). However, in view of the low temperatures and the slaking action of precipitation at this time it would not be very significant. With the onset of the season of high temperatures the surface of the takyr usually loses any algal film it might have, even a "dense" algal film. With drying it curls up and is mostly scattered by the wind. Algae require time for growth and film formation, which naturally take place after precipitation. But by then all the trapped air has been removed and the pores are filled with water.

For a more detailed study of the formation of porosity, a series of experiments was set up to reproduce takyr crusts, with their proper morphology, under artificial conditions. To prevent the action of any biological agents the soil was sterilized. Samples of the crusts mentioned above from a depth of 0 to 5 or 6 cm. were put through a 1 mm. mesh, then placed in oilcloth bags and sterilized in an autoclave for 1.5 hours at 1 atmosphere. Confirmatory seedings of the material in Bristol solution and meat infusion broth showed its complete sterility. The experiments were carried out in six treatments with different preparations and drying conditions.

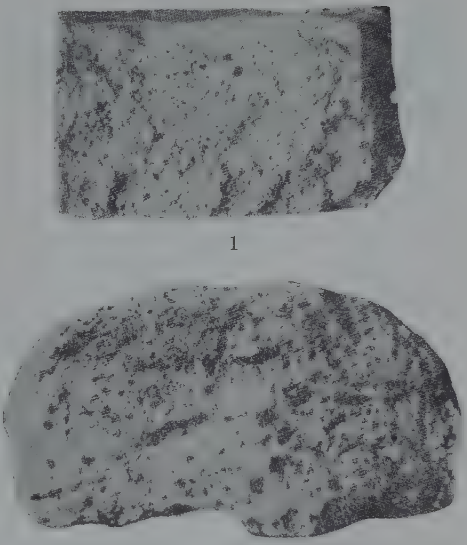
In the first series of experiments the ground dry soil was placed in a low, wide glass crystallizing dish and distilled water was sprayed on from a sprinkler until a layer of water 0.5 cm. deep was formed on top. Some of the crystallizing dishes were placed in a constant-temperature oven at 60° to 65° and some were subjected to drying in the open air under 300 watt electric lights which heated the surface to 55°.

In the second series of experiments with the same samples a thin suspension of soil was added to the surface of the prepared beakers. In the last treatment the soil was mixed with distilled water in a tall glass jar and carefully stirred for two hours so as to displace as thoroughly as possible the air of the pores of the soil. Then the suspension was transferred to crystallizing dishes and dried by the two methods mentioned before.

Cellular porosity was observed in all the treatments, but the takyr crust most morphologically similar to the natural, was formed in the last treatment with prolonged stirring of the suspension and subsequent drying in the constant-temperature oven.

Figure 1, *1* shows an artificially formed takyr crust (slightly enlarged). The only visible difference between it and the natural (Fig. 1, *2*) was the somewhat smaller size of the pores, obviously explained by the small volume of soil taken for the experiment.

A critical scrutiny of the experiment results allows us to assume that prolonged stirring of the suspension with exposure to air led to a certain change in its salt composition as a result of saturation by some gaseous component of the air. This component obviously can only be carbon dioxide gas since its solubility, compared to that of other components of the air, is relatively great. Considering that the suspension was prepared with distilled water which had not been thoroughly boiled and thus contained carbon dioxide, and that it had an alkaline reaction (pH = 7.9), absorption from the air could have been considerable. Saturation of the suspension by carbon dioxide led to a shift in the equilibrium in which a part of the carbonates could have gone into solution in the form of bicarbonates.



1

2

FIG. 1.—Porous takyr crust. 1. Vertical section through an artificially prepared crust. 2. Part of a natural takyr crust.

The subsequent drying out accompanied by heating led to decomposition of the bicarbonates according to the following reactions:

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

$$Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$$

To confirm this hypothesis a supplementary experiment was set up using the artificial crusts formed in the last treatment. The suspension prepared from it was boiled over a low flame for two hours to decompose the soil bicarbonates as completely as possible. During the boiling very violent foaming was observed. After boiling the suspension was cooled over soda lime to a temperature of 35° to 40° and then quickly placed in crystallizing dishes and put into the warm constant-temperature oven where it was dried at 60°. The crust formed was completely devoid of pores visible to the naked eye; it was cemented and very tough and was dissected by a large number of broad cracks (Fig. 2). The crust was only half as thick although the same quantity of soil was used to form it.

The results of the last experiment fully confirm the hypothesis that the pores are caused by carbon dioxide given off by the decomposition of the bicarbonates of calcium and sodium when the crusts dry out. The preliminary decomposition of the bicarbonates by prolonged boiling of

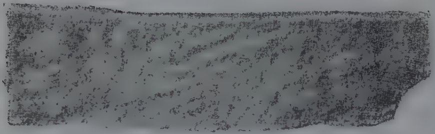


FIG. 2.—Vertical section through a takyr crust made artificially after removing carbon dioxide gas from the sample.

the water suspension and removal of the CO_2 formed kept the pores from forming.

The second section of our work was devoted to a study of the possibility of formation of pores in takyr crusts by the method presented in the paper by Bazilevich, Gollerbakh, Rodin and Zemskii (2). For this the takyr crust was previously dried at 160° to 180° and then used for the preparation with boiled distilled water of a viscous soil mixture, placed in a 1 cm. layer on the bottoms of small crystallizing dishes. The surface of the layer was treated with an algal film consisting principally of *Phormidium autumnale* with admixtures of *Microcoleus vaginatus, Pleurococcus vulgaris* and *Hantzschia amphioxys*. In some of the dishes an almost pure culture of *Phormidium autumnale* was applied.

A nutrient solution was added to the dishes and they were placed in diffuse light at room temperature. They received direct sunlight only for two hours in the morning.

As early as the tenth day after beginning the experiment a fairly thick algae film had been formed. Clay was added in a thin suspension of sediment prepared with thoroughly boiled water and soil dried at 160° to 180°.

During the course of the work it became apparent that applying a very thin layer of clay (0.5 to 1.0 mm.) was not sufficient to cause it to accumulate on the film, since the film floated on the surface borne by numerous bubbles of oxygen given off in photosynthesis. We were successful in covering the film with clay only when the nutrient solution was applied with a siphon, in which case the film settled directly on the soil surface. For the clay covering it was necessary to use a thicker suspension than that tried initially. Notwithstanding these difficulties the bubbles of oxygen were covered over with clay and there was even an opportunity to observe this process through the walls of the crystallizing dishes. However, within two or three hours after the bubbles were covered with clay, those located at the wall of the vessel disappeared. It is not clear whether this took place with the bubbles at the center of the crystallizing dishes. After the clay had been deposited the crystallizing dishes were again placed in the light until a new film had developed on their surfaces 5 to 6 days later. This procedure for depositing clay was repeated several times. When the layer of clay-covered films reached a thickness of 2 cm. the crystallizing dishes were placed in the constant-temperature oven to dry at 60°.

The crust formed after drying did not contain any traces of clay-covered bubbles of gas. There was no porosity at all in the crust, just as there was none in the experiment in which the suspension was subjected to boiling for two hours. In contrast to the preceding experiment, the crust formed on deposition of clay on the algal films was clearly layered and the layers retained the green coloration on surfaces exposed by fracture. The number of layers corresponded in general to the number of times clay had been deposited.

Evidently the bubbles of gas enclosed by clay (providing they were preserved before drying) were removed considerably before the soil acquired a consistency viscous enough to retain them.

The results of this experiment prove that if algae take any part in the formation of porosity, it is only an indirect one as simultaneous producers and consumers of CO_2.

Yelenkin (8), citing the work of Bąchmann (1912) and Nadson (1927), refers to possible ways in which blue-green algae participate in the destruction of limestone rocks and the formation of pores within them. In essence the algae, giving off organic acids, decompose $CaCO_3$ with the formation of CO_2. The latter in turn transforms $CaCO_3$ into bicarbonate which is leached by precipitation and which forms cavities in the rock.

A similar process may go on under the action of the CO_2 given off by the algae in respiration without participation by organic acids (which are produced only by certain species). The respired-CO_2 pathway is the most probable under the conditions discussed here. However, without excluding the indirect participation of algae in the formation of pores in takyr crusts, it must be noted that the scale of this activity is extremely small. Our experiments showed that culturing algae for a month and a half on saline and carbonate soils did not exert any effect on the equilibrium of salts in the system: calcium and sodium carbonates $\rightleftharpoons$ calcium and sodium bicarbonates. In contrast, increasing the content of alkali and alkaline earth bicarbonates in the soil solution led to the formation of pores in the crust, even though in insignificant numbers.

On the basis of the experimental data obtained, formation of pores in takyr crusts under natural conditions may be explained as follows: An especially clear and characteristic cellular structure is observed in takyrs of mature age which have developed from chloride solonchaks with far-advanced decomposition of the aluminosilicate part of the colloidal complex. Young takyrs usually have a fine-porous crust. Mature takyrs have high alkalinity of the upper part of the profile.

Bazilevich (4) cites data showing a very high content of bicarbonates in the crusts of solonchak takyrs (1.31 to 1.41 me. of HCO_3 per 100 g. of soil). After rain has fallen, the sun's rays warm the entire top layer drying out the takyr. The exposed surface of the takyr is warmed quickly and intensively. Bicarbonate salts present in the soil solution as unstable compounds begin to decompose even with slight warming according to the reactions cited. It is not impossible that some of the CO_2 is also removed by absorption by the algae in the process of photosynthesis.

The CO_2 given off shifts the equilibrium and the solution gradually becomes richer in soda (Na_2CO_3). Research by Bazilevich, Degopik and Kryukov (3) on the dynamics of the alkalinity of the atmospheric water stagnating on the surface of the takyr showed its rapid increase with time, in some cases reaching 7.70 grams per liter of HCO_3 of which 7.03 grams per liter is carbonate alkalinity titrable with phenolphthalein.

Secondary carbonates of calcium formed as a result of the decomposition of $Ca(HCO_3)_2$ by warming are precipitated.

Feofarova (11) noted a large amount of secondary carbonates in the form of powdery calcites. It is interesting that it has been established micromorphologically that there is carbonate removal from the pores, but no cementing of them by secondary finely dispersed $CaCO_3$ as stated by Bazilevich, Gollerbakh, Rodin and Zemskii (2). This fact indirectly confirms the nature of the gas formed in the pores.

Carbon dioxide gas from the soil strives to escape to the atmosphere, but the rapidly increasing viscosity of the medium prevents this. The bubbles of gas at the very surface, acquiring great energy because of thermal expansion, exceed the surface tension of the film of suspension and explode from the inside forming craters. The bubbles below are not capable of overcoming the obstruction and, expanding to the limit for the given temperature, remain in place as pores after the soil has dried out.

The decrease in pore size usually observed in the lower, less intensively heated portion of the crust of takyrs becomes understandable if consideration is given to the thermal coefficient of expansion of gases.

A well-developed algal film may also hinder somewhat the escape of gas and make possible the formation of pores, but if it is a major hindrance, then a maximum number of pores should be concentrated directly under it in a 1 to 2 mm. layer. Observation shows, however, that both moist and dry algal films separate quite freely and the first 1 to 2 mm. beneath them are most often devoid of pores.

Porosity becomes conspicuous only below 3 to 5 mm. and is scattered over the entire thickness of the crust.

Thus, according to our conception, the formation of pores in the takyr crust has a certain remote resemblance to the formation of pores in fresh dough on the addition of sodium bicarbonate or ammonium carbonate.

Conclusions

1. Formation of the unique "dry-bread" porosity of takyr crusts is related by most investigators to purely physical processes. Its occurrence is explained by the action of the compressed air of the soil displaced by moisture from atmospheric precipitation under the specific hydrothermal desert conditions.

More recently certain authors have attributed a leading role in this process exclusively to biological factors, relating the formation of pores to the biochemical activities of algae.

2. Our research showed that the formation of pores takes place basically as a result of physicochemical processes in the presence of carbonates under the contrasting temperature conditions characteristic of deserts.

3. Pores are formed in takyr crusts by the drying out of the takyrs following heavy rains, with high air temperatures next to the soil and

intense and direct insolation. The concrete cause of pore formation is the carbon dioxide gas given off in the conversion of bicarbonates to carbonates when the soil solution temperature is raised.

4. Carbon dioxide of biological origin plays a subordinate role in the formation of pores, since the amounts of it given off are negligible in view of the general inhibition of biological processes in takyrs.

The bubbles of oxygen, given off in abundance by algae in photosynthesis, do not participate in the formation of pores.

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SOME DISTINCTIVE GENETIC AND PROVINCIAL CHARACTERISTICS OF TYPICAL CHERNOZEMS OF THE NORTHWEST ALTAI

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TYPICAL chernozems[1] are distributed in large areas and in small spots on the gently sloping piedmont, foothill plateaus, and plains at the foot of mountains in Northwest Altai. They are found in Altai territory between the lower reaches of the Katun river and the headwaters of the Alei river (Fig. 1), extending to Kazakhstan border.[2]

In Altai territory these soils cover about 250,000 to 300,000 hectares.

The soils of the northwest Altai piedmont were first described by Vydrin and Rostovskii (4). In their terminology typical chernozems fell largely into the series "chernozems with a humus content of 10 to 18%." Some information about these soils is found in papers by Smirnov (20), Petrov (15) and Rozanov (18). Typical chernozems are found on lands fully enclosed in the areas shown on the State Soil Map (7) as "northern rich" (that is, thick and medium thick) chernozems and in part in the areas of "ordinary medium-humus thick" and "mountain leached" chernozems.

The soil profiles under description consist of a deeply colored dark-gray horizon, tinged with a faint brownish shade under humus ($A + B_1$), 70 to 90 cm. thick, with an unevenly colored B_2 horizon 10 to 20 cm. thick and a brown B_3 horizon which forms a gradual transition into parent material.

Typical Altai chernozems have a fine clay loam texture (Table 1) with characteristics of a loess-like material, becoming fainter with an increase in the altitude. In the piedmont and foothills the upper part of the profile (especially the center of the humus horizon) is more clayey (Fig. 2). This is not noted in similar soils in the European part of the USSR (17, 2, 3 and others) although Prasolov (17) has stated that it should be possible to expect clay deposition in the upper part of chernozem profiles.

The upper part of the profile is characteristically of finer texture in other subtypes of Altai chernozems (southern, ordinary, and leached). In 14 profiles of 19, texture analysis established the presence of clay in the upper profile; in three profiles it was difficult to establish the presence or absence of clay because of the large intervals between samples, and in only two profiles on fine-textured parent material (medium clays) there was no clay deposition. The heaviest clay deposition was manifested in soils developed on coarse-textured (medium clay loam loess) parent material in more moist regions. On fine-textured (strongly weathered) parent materials, clay deposition develops slightly or not at all.

According to data from Petrov (14), loess-like deposits of the Altai piedmont were formed under arid conditions and are distinguished by their slight weathering. It is natural to assume that the loess-like deposits of the Altai, rich in primary minerals, would be subjected under more moist conditions to further weathering and clay deposition within the upper soil horizons.

The humus profile of typical chernozems (Table 2) is distinguished by its great thickness and gradual decrease in humus content with depth. This is characteristic of the western districts of the chernozem zone of the USSR, but not of Siberian chernozems. The carbon-nitrogen ratio does not deviate noticeably from the characteristic values of chernozem types.

In the 0 to 20 cm. layer, the humus content corresponds from 160 to 200 metric tons per hectare (or, in the top one meter layer, from 500 to 700 metric tons per hectare). The nitrogen content is 8 to 12 metric tons per hectare, including 150 to 500 kg. of hydrolyzable nitrogen. Total phosphorus is 4 to 6 metric tons per

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[1] Different meanings are attributed to the term "typical chernozems". At the All-Union Conference on the Cartography and Nomenclature of the Soils in 1950, rich and thick chernozems were combined under the designation "typical". In the present article the term "typical chernozems" is used in this sense.

[2] We describe typical chernozems only within the limits of Altai territory.

TABLE 1

Texture of typical chernozems (Allowance made for losses during processing)

Description of soil and section number	Depth of sample, cm.	Content of fractions (in mm.) in percent						
		>0.25	0.25 to 0.05	0.05 to 0.01	0.01 to 0.005	0.005 to 0.001	<0.001	<0.01
Chernozem; typical, medium humus, thick. Plain at foot of mountain. Section 293	0–20	0.2	5.1	35.1	11.2	16.9	31.5	59.6
	23–35	0.4	0.8	40.4	14.5	15.9	28.0	58.4
	40–50	0.1	1.5	33.7	10.6	20.4	33.7	64.7
	80–90	0.0	4.7	39.7	11.0	13.4	31.2	55.6
	140–150	0.0	1.5	48.9	12.4	12.0	25.2	49.6
Chernozem; typical, medium humus, thick. Piedmont. Section 295	0–10	0.0	2.9	38.9	10.0	18.8	29.4	58.2
	20–30	0.0	9.0	31.9	12.0	16.5	30.6	59.1
	45–55	0.0	4.2	33.4	10.9	17.2	34.3	62.4
	90–100	0.0	7.3	34.5	11.6	13.1	33.5	58.2
	130–140	0.0	2.8	43.5	8.3	14.9	30.5	53.7
	190–200	0.0	3.0	36.3	11.5	8.3	40.9	60.7
Chernozem; typical, rich, thick. Foothills. Section 299	0–20	0.2	4.2	30.2	11.1	19.3	35.0	65.4
	25–35	0.2	2.6	31.0	9.7	21.4	35.1	66.2
	40–50	0.2	5.6	20.9	22.6	12.8	37.9	73.3
	80–90	0.1	15.5	29.5	11.3	10.1	33.5	54.9
	155–165	0.4	1.3	29.0	15.0	13.1	41.2	69.3

hectare, of which 200 to 700 kg. is available. Available potassium is 400 to 800 kg. per hectare. Together with other properties, these indices allow us to include typical Altai chernozems in the group of soils with very high natural fertility.

The exchange capacity attains maximum values in the horizons below the plow layer. The amount of exchangeable Ca^{++} in the upper layer of the humus horizon changes little, since here, along with a decrease in the humus content going down the profile, the amount of clay particles increases. In the lower part of the humus horizon, where the decrease in the humus content is not compensated by an increase in the content of clay particles, the amount of exchangeable Ca^{++} quickly decreases with depth The distribution of adsorbed Mg^{++} does not show any clear pattern. The amount of exchangeable K^{+}, as usual with chernozems, quickly decreases with depth of profile.

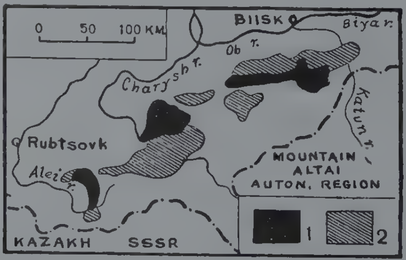

FIG. 1—The distribution of typical chernozems on the northwest piedmont of the Altai. 1—Regions in which typical chernozems predominate. 2—regions in which typical chernozems are often encountered.

The reaction of typical chernozems is neutral. Parallel determinations of the pH values at the same points in 1955, a dry year, and 1956, which was moist, showed a noticeable decrease in pH in 1956 (from 6.8 to 7.3 and 6.3 to 6.7 in the upper part of the profiles of sections 293 and 295). However, because of the small number of determinations (at only two points) these data require further confirmation.

The peculiarities of the carbonate profile are micellar segregation of carbonates, a faintly expressed maximum of carbonates, and a relatively constant maximum amount of CO_2 (usually not more than 5 to 6%). Fig. 3 shows that the carbonate contents in the soil profile and the corresponding volume of parent material are almost equal (an increase in the $CaCO_3$ content of the upper carbonate horizon is compensated by the absence of carbonates in the upper horizons). Therefore, we speak of these soils as originating from "immemorial" steppes.

We have not been able to carry out fixed observations on the migration of carbonates, but the facts indirectly show the presence of such translocations. In 1955 effervescence began between the middle and lower edge of the humus horizon. It averaged 20 to 30 cm. higher than in 1956, a wet year, when the beginning of effervescence coincided approximately with the lower edge of the humus horizon (with very small variations on either side). Further, in 1955 there was observed in all soil profiles an effervescent

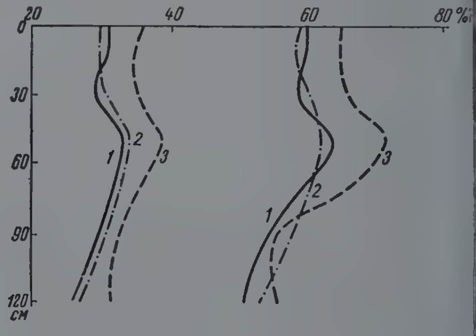

FIG. 2—Content of clay fraction (left) and physical clay (right) in typical chernozems. 1—Plain at foot of mountain (Section 293); 2—Piedmont (Section 295); 3—Foothills (Section 299).

TABLE 2

Some data from analyses of typical Altai chernozems (ND = not determined)

Location and sect. no.	Depth of sample, cm.	Humus, % (Tyurin)	Total nitrogen, %	pH of water suspension	CO_2, %	Exchangeable cations, me.				
						Ca^{++}	Mg^{++}	K^{+}	H^{+}	Total
iedmont, tilled. Section 295	0–10	8.45	0.53	7.23	none	43.1	4.1	0.7	ND	47.9
	20–30	7.77	0.51	7.25	none	43.5	4.6	0.3	ND	48.4
	45–55	6.09	0.48	7.50	0.48	ND	ND	ND	ND	ND
	65–75	4.40	0.31	7.50	1.93	ND	ND	ND	ND	ND
	90–100	1.80	0.21	7.88	5.63	ND	ND	ND	ND	ND
	130–140	0.72	ND	7.82	5.42	ND	ND	ND	ND	ND
	190–200	0.54	0.12	7.90	5.86	ND	ND	ND	ND	ND
lain at foot of mountain; tilled. Section 293	0–20	8.80	0.46	6.80	none	38.4	2.0	0.6	ND	41.0
	25–35	7.83	0.44	7.03	none	36.2	4.6	0.3	ND	41.1
	40–50	5.60	0.30	7.33	none	32.3	5.4	0.3	ND	38.0
	65–75	3.21	ND	7.19	none	ND	ND	ND	ND	ND
	80–90	1.16	ND	7.05	0.20	25.8	3.8	0.2	ND	29.8
	100–110	0.79	ND	7.71	4.83	ND	ND	ND	ND	ND
	140–150	0.66	ND	7.77	5.12	ND	ND	ND	ND	ND
oothills; tilled. Section 299	0–20	9.93	0.55	6.94	none	42.3	5.6	1.8	0.2	49.9
	25–35	8.01	0.46	7.00	none	45.1	9.1	0.8	0.2	55.2
	40–50	6.81	ND	7.05	none	45.0	2.8	0.8	0.2	48.8
	60–70	4.51	ND	7.16	0.15	ND	ND	ND	ND	ND
	80–90	2.60	ND	7.49	6.00	ND	ND	ND	ND	ND
	115–125	ND	ND	ND	5.71	ND	ND	ND	ND	ND
	155–165	ND	ND	ND	5.12	ND	ND	ND	ND	ND
iedmont; tilled. Section 287	0–20	9.59	0.78	7.07	none	45.5	3.3	1.0	ND	49.8
	25–35	6.90	ND	7.21	0.19	44.9	6.6	0.7	ND	52.2
	50–60	4.25	ND	7.93	1.90	ND	ND	ND	ND	ND
	70–80	1.08	ND	ND	4.40	ND	ND	ND	ND	ND
	130–140	0.80	ND	ND	5.72	ND	ND	ND	ND	ND
lain at foot of mountain; tilled. Section 167	0–20	9.77	0.51	ND	none	37.0	5.6	1.3	ND	43.9
	20–30	8.17	0.45	ND	none	38.6	3.7	0.9	ND	43.2
	40–50	5.62	ND	ND	none	34.4	1.9	ND	ND	36.3
	70–80	2.28	ND	ND	0.15	29.2	2.8	ND	ND	32.0
	105–115	1.29	ND	ND	8.62	ND	ND	ND	ND	ND
	140–150	0.65	ND	ND	7.85	ND	ND	ND	ND	ND

orizon 20 to 30 cm., even greater in thickness nd devoid of any visible segregation of carbon-tes. In 1956 it completely disappeared[3] and ef-ervescence coincided with the beginning of car-onate segregation.

The migration of carbonates may be related o abrupt differences in moisture received by the oil in summers of different years. Thus in the owns of Zmeinogorsk and Biisk (in the south-vestern and northeastern borders of the sub-one) precipitation from May to August, 1954, vas 250 and 358 mm. respectively; in 1955, 95 nd 85; and in 1956 in May and June alone (we ave no later data) 153 and 163. Consideration nust be given to the higher evaporation rate n dry years. In 1954 and 1956 moisture in the pper soil horizons in Zmeinogorsk district was igher all summer than in the 50 to 100 cm. ayer (where the carbonates appear). In 1955 it dropped at the middle of June and remained low until fall. The diffuseness of the upper boundary of the carbonate profile shows an upward migration of carbonates in 1955. (Table 2, sections 295 and 287, in which effervescence begins much higher than the horizon with the maximum of carbonates). All these data, in our opinion, suggest an annual translocation of carbonates in typical chernozems of the Altai.

Easily soluble salts evidently lie fairly deep in typical chernozems. Borings in two sections (down to 360 and 405 cm.) showed no deposits of gypsum or other salts.

Typical Altai chernozems have a well-expressed large-grained structure[4] which is, however, strongly degraded by thorough plowing. (Table 3). Most of the fine particles of silt produced by destruction of the 2 to 5 mm. fraction in the plow layer go into the formation of very unstable large clods bigger than 10 mm. The plow layer structure has a low water-stability, but that of the subsoil is considerably higher.

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[3] It should be noted, however, that the number of ections compared to reach this conclusion was mall: 8 in 1955 and 12 in 1956.

TABLE 3

Aggregate content of typical chernozems (Size of particles and aggregates in millimeters)

Section No.	Depth of sample, cm.	Air-dried soil								In water					
		>10	10–5	5–3	3–2	2–1	1 to 0.5	0.5 to 0.25	<0.25	>3	3–2	2–1	1 to 0.5	0.5 to 0.25	<0.2
293, tilled	0–20	37.5	11.3	9.2	7.9	9.8	7.7	10.0	6.6	1.0	1.7	6.6	12.0	35.9	42.
	25–35	0.0	3.7	28.5	28.2	18.1	7.1	7.2	7.2	8.3	18.3	25.0	8.6	18.2	21.
287, tilled	0–20	21.7	11.0	12.8	13.8	14.6	8.7	11.5	5.9	8.2	13.6	24.0	18.0	13.9	22.
	25–35	1.0	9.9	32.6	26.7	15.1	5.6	5.6	3.5	22.2	20.2	16.2	9.2	7.4	24.
266, virgin	0–10	1.2	21.2	32.1	16.5	11.8	5.4	6.4	5.4	49.1	13.9	10.8	6.5	3.3	16.

Outstanding for its especially high waterstable structure is section 266, which is generally characteristic of the low mountains of the Altai.

The varieties of typical chernozems which effervesce at the greatest depths (sections 293 and 167) and are located on plains at the foot of mountains have some unique characteristics. The conspicuous gap between the ending of the humus horizon and the beginning of effervescence, and their smaller exchange capacity, make them resemble leached chernozems. However, according to all other signs this group is related to typical chernozems and is clearly distinguished from the leached chernozems of other territories by having a weakly acid reaction, noticeable clay deposition in the humus horizon, a different kind of distribution of adsorbed cations in the profile and, in a number of cases, traces of an admixture of silica.

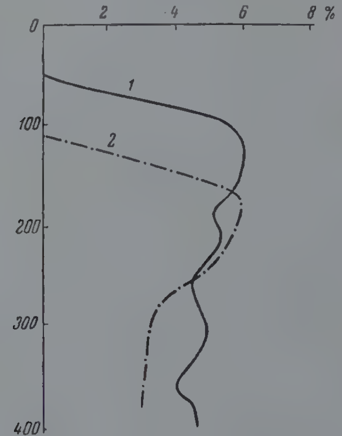

FIG. 3—Content of CO_2 as percent in typical chernozems. 1—Piedmont (Section 295); 2—Plain at foot of mountains (Section 293).

On the basis of our information (more than 100 determinations of the thickness of the humus horizons and about 40 soil profiles with analysis of the humus content) we can subdivide typical chernozems of the Altai into three types: rich thick, rich medium thick and medium-humic thick.[5] The greatest thickness (usually 80 to 90 cm.) is distinctive of the typical chernozems of the southwestern part of the subzone. They have the lowest humus content (7 to 9%). Rich medium-humic chernozems (60 to 70 cm. thick) occur widely in the northeast (on the plains at the foot of mountains). Rich thick chernozems (with 9 to 10% humus content and 70 to 90 cm thick) predominate in the remaining parts of the subzone.

There is a decrease in thickness and an increase in humus content of other subtypes of Altai chernozems (from the southern to the podzolized)[6], on moving from the southwest to the northeast. This indicates noticeable provincial differences even within this comparatively small area.

In comparing typical chernozems of the Altai with similar soils of other regions of Siberia, it is not worthwhile considering the southern, solonetz, solodized, podzolized, "puffed" (meadow-chernozem soils) or other types of chernozems clearly not similar to those which interest us. Leached chernozems (leaving aside the thinnest,

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[4] The formation of soil structure in the adjacent western part of the Altai has been considered in detail in Sokolov's monograph (21).

[5] In accordance with the gradations accepted by the Special Group Expedition, working in the Altai region in 1954 and 1955, we are including among the rich chernozems those with a humus content of more than 9%, and among the thick chernozems those with a humus horizon more than 70 cm. thick.

[6] This idea is confirmed by a large amount of factual material.

the "pocketed" and the structureless types), with all their variety, differ from the typical chernozems not only by a definite gap between the humus and carbonate horizons but also by the presence of illuvial horizons, a weakly acid reaction, traces of silica admixture and, in addition, by considerably less thickness.

Let us examine the chernozems described in Siberia under the designations "ordinary" and "slightly leached." Ordinary chernozems are distributed on the Western Siberian Lowland, including the foreland of the Ob plateau, and in the Minusinsk basin.[7]

Among the ordinary chernozems of Western Siberia (5, 6) the predominant ones are the thin, structureless varieties occurring in strips and having relict illuvial horizons (residues of past solodization); in their properties they are remote from the typical Altai chernozems. Ordinary chernozems of the Ob foreland plateau, not occurring in sharply expressed belts and not having relict illuvial horizons, differ from typical Altai chernozems not only in having considerably less thickness and less humus content but also by smaller exchange capacity, by a clearly expressed maximum of carbonates coinciding with a horizon of white specks—characteristic circular accumulations of carbonates—and, in a number of cases, by the superficial occurrence of gypsum. Ordinary chernozems of the Minusinsk basin (8), not having deposits of carbonates in the form of white specks or a pronounced maximum of carbonate salts, differ from Altai chernozems by their lack of thickness, the abrupt decrease of humus content and exchangeable cations with depth in the profile, and by a very high content of adsorbed magnesium (about 20% of the exchange capacity). According to the conditions under which they were formed, "ordinary rich" chernozems found in the Minusinsk basin, bear certain characteristics of meadow conditions (distribution along the hollows of slopes and terraces above meadows) and are distinguished by a very sharp decrease of exchange capacity and amount of humus with depth in the profile and also by a high content of adsorbed magnesium (up to 20%).

The "slightly leached" chernozems of the Western Salair Foreland (16) and the northwestern Kuznets basin[8] (8), differ from ordinary chernozems by their high humus content and from leached chernozems by the absence of illuvial horizons and neutral reaction. They might be called representatives of the most continental province of the subzone of typical chernozems. Characteristic of "slightly leached" chernozems is an even lower boundary of the humus horizon without pockets or convolutions. This is also characteristic of typical chernozems of the Altai but *not* of most Siberian chernozems. However, the thinness of the humus horizon (40 to 50 cm.), the sharp decrease with depth in humus content and exchange capacity, and the increased deposition (at least in Kuznets basin chernozems) of gypsum, distinguish the "slightly leached" chernozems from the typical Altai chernozems. Somewhat closer to "slightly leached" chernozems are the medium-thick varieties of typical chernozems with a considerable gap between the humus and carbonate horizons. The latter varieties are located in the extreme northeast of the subzone of typical chernozems on the Altai piedmont.

The belt of typical chernozems is not limited to the Altai territory but is also observed in Kazakhstan along the western Altai piedmont. Typical chernozems of the western piedmont, described as "ordinary" (1), "mountain" (15) or "thick medium-humic" (21) are characterized by great thickness (80 to 100 cm.) and low humus content (6 to 8%). According to these indices they are close to the adjoining soils of the southwestern subzone of typical chernozems of Altai territory.

Thus, according to existing data, typical chernozems within Siberia are located only on the Altai piedmont and are observed as a discontinuous 400 km. arc from the lower reaches of the Ul'ba river to the lower reaches of the Katun river. The prolongation of this arc in a northeasterly direction is the spot of "slightly leached" chernozems. According to their properties they are evidently related most closely of all the Siberian chernozems to the typical chernozems.

The typical chernozems of the Altai meadow steppe, do not find their counterpart among any of the geographically adjacent soils of Siberia,

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[7] Thin, ordinary chernozems occurring in strips ("tongues") are also encountered at some places in islands of forest-steppe in Central Siberia.

[8] "Slightly leached" chernozems are also described in western Siberia (7). No clear differences between them and leached chernozems were noted, aside from a less pronounced illuvial horizon.

TABLE 4

Characteristics of the humus profiles in different regions of the Altai piedmont

Subtypes of chernozems	Western piedmont		Northern piedmont		Northeastern piedmont at junction with Salair ridge	
	Humus content, %	Thickness of humus horizon, cm.	Humus content, %	Thickness of humus horizon, cm.	Humus content, %	Thickness of humus horizon, cm.
Southern	4–5	50–60	5–7	30–40	none	
Ordinary	5–6	60–70	6–8	45–55	none	
Typical	6–8	80–100	9–10	70–90	none	
Leached	7–8	80–100	9–10	70–90	11–13	50–70

but are in many respects similar to the typical chernozems of a number of European regions of the Soviet Union, which were also formed under meadow steppes. With respect to thickness of the humus horizon and humus content, exchange capacity and composition of adsorbed cations, reaction, forms of carbonate separation and depth at which salts are deposited, the typical chernozems of the Altai are similar to their counterpart soils of the Central Russian or Volga foreland heights (17, 2, 13, 19, 9). The typical chernozems of the Altai are distinguished only by their larger, more water-stable structure, by the deposit of some clay in the upper part of the humus horizon and, evidently, by greater mobility of the carbonates.

The differences between typical Altai chernozems and the chernozems of other regions of Siberia are related to the differences in the conditions under which they were formed. Because it is impossible to consider the entire complex of natural conditions of the areas described, we will restrict ourselves to the special climatic characteristics. Atlantic cyclones, dying away above the broad plains of Western Siberia and Eastern Kazakhstan, sharply intensify their activity on approaching the Altai piedmont. As a result of this the climate of the piedmont is more mild and moist. The annual precipitation in this subzone is 500 to 600 mm., 1.5 to 2 times as great as in the subzone of the ordinary and leached chernozems on the Western Siberian plains. The total precipitation of the cool half of the year (150 to 200 mm. and more) is two to three times as great. The average January temperature in this subzone is −14° to −16°, as against −19° to −21° on the adjacent plains. The massive snow cover (50 to 70 cm.) in combination with the relative mildness of the winter temperatures prevents the typical chernozems from freezing severely or deeply. The moist and cooler summer keeps them from drying out much. Climatic conditions account for many of the distinctive features of typical Altai chernozems which are not characteristic of the chernozems of other regions of Siberia.

The difference between the typical chernozems of the Altai and their counterparts in the European part of the USSR depend precisely on the conditions under which they were formed. Distinctive features of the structure are related not only to the effect of biological factors but evidently also to the fine texture of the parent material and, possibly, to the climatic conditions. Clay deposition, as noted before, results from slight primary weathering of the loess-like material of the Altai deposits. We relate the high mobility of carbonates to the sharp contrast of moisture conditions in the summers of different years.

The chernozem zone of the Altai piedmont is in many respects a repetition in miniature of the corresponding zone of the European part of the USSR (not including its western, most continental districts). All the "zonal" subtypes of chernozems from the southern to the podzolized and, in addition, clear differences of a provincial type can be found here. On the basis of sources in the literature (1, 15, 21) and our own data, we present in Table 4 the distinctive characteristics of the humus profiles in the different regions of the Altai piedmont (showing the most characteristic average figures).[9]

The table shows clear differences between the chernozems in various parts of the Altai piedmont. The question arises: is it possible to relate them to a single soil province? Further, does the Altai piedmont district of the chernozem zone with typical and thick leached chernozems differ more abruptly from the adjoining districts of the Siberian chernozem zone than do the adjoining soil provinces differ among themselves?

In conclusion we note that even a brief review of the Siberian chernozem zone (including the Altai piedmont) convinces us of the enormous variation of Siberian chernozems, which is quite natural for an area so vast and with such varying natural conditions.

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[9] We have not considered podzolized chernozems because of some contradictory data for the western Altai piedmont.

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BASIC SOIL GROUPS OF THE DZHUNGARIA AND THE ADJOINING TIAN SHAN AND ALTAI MOUNTAINS

P. S. Panin

Dzhungaria is located between the eastern spurs of the Tian Shan, the Mongol Altai, and the Dzhungarian mountains and is one of the inland basins of Central Asia. This entire district, called Northern Sinkiang, is three to four thousand kilometers distant from seas and oceans and is in the zone of the Central and Middle Asian deserts. This determines the desert character of the climate and the low humidity of the adjoining regions of the Tian Shan and the Altai. The combination of mountain and plain relief, the dryness of the climate, and the variation in parent materials have caused a specific combination of soil types and zones of vegetation.

In this article we will briefly characterize the basic soil groups of Northern Sinkiang and give their zonal distribution.

The study of the soils of Sinkiang began comparatively recently. In 1944–1945 they were investigated by Ma Yun-chzhi (4–7), who devoted most of his attention to the mountain soils of Tian Shan. In 1956 he described the soil cover from the piedmont to the central part of the desert depression of Dzhungaria. On this profile the hilly piedmont of the Tian Shan and its lenticular stone-and-gravel deposits (called locally "gobi") are related to the zone of typical and light sierozems in the belt where the ground water tapers out; below the belt of gobis may be distinguished meadow sierozems; further down into the desert there are desert sierozems among which are encountered brown solonetz soils which the author said "could be takyrs" (7).

In 1949 Sinkiang was visited by the soil scientist Si Tsen-fan who studied conditions for growing kok-sagyz in the basin of the Ili river, described meadow and chestnut soils and also considered the presence in this region of mountain chernozems (9).

Starting in 1956 the Academy of Sciences of the Chinese People's Republic began composite investigations in the mountain region of the Altai (2). On the preliminary soil map of the southern slopes of the Mongol Altai which was shown by Prof. Li Lyan-pe at the All-China Conference of Soil Scientists in 1956, twelve soil groups and complexes were distinguished.

In addition to the research mentioned above, soil investigations have been made in the last two years on different parts of the Dzhungaria to formulate a plan for using the water of the lower reaches of the Urumchi and Manas rivers and also to organize state farms. The present article also uses data from the author's personal observations, obtained during a two-month stay in this mountainous and desert district.

High-mountain Tundra Soils. The high-mountain tundra lies above the snow line and covers the district of perpetual ice and glaciers. In the Tian Shan mountains, according to Ma Yun-chzhi (5), it begins on the southern slopes at an altitude of 3500 m., on the northern slopes at 3300 m. In the Altai it descends to 3000 and 2800 m. respectively. Ma Yun-chzhi notes that in this zone is found frost weathering, glacial forms of the relief (karri[1]), rocks and coarse glacial deposits; only between mountains are small spots of shallow soil deposits found. On these deposits primitive high-mountain soils develop. Usually such soils are encountered on the southern slopes, where the snow cover accumulates in small quantities and melts quickly in the hot months, while on the northern slopes the snow and ice remain the year round. In this zone and below it near the snow line only lichens and mosses grow (3). The soils under the mossy cover have a light-brown coloration and a skeletal sandy loam texture and effervesce weakly with hydrochloric acid. Ma Yun-chzhi states (5) that in some places these soils are distinguished by a thin, dark-brown humus horizon with half-decomposed organic residues. The weak leaching and insufficient humification of organic substances of the soils of this zone are undoubtedly explained by the permafrost of the lower layers of the parent material, which inhibits the development of microbiological processes and the gravitational movement of water.

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[1] Karri are forms of relief containing deep or shallow furrows separated by sharp ridges or partitions.—Translator.

According to these characteristics, the high-mountain soils of Tian Shan and the Altai resemble the desert-alpine soils described by Bogatyrev (1). The desert-alpine soils are distributed in the upper belt of the alpine zone—below the snow line. The soils we are describing lie higher than the snow line and develop under colder conditions, possibly with daily thawing and nightly freezing during the summer. The high-mountain soils of the Tian Shan and the Altai develop under more moist conditions than do the high-mountain soils of the cold deserts of Tibet where there is very low relative humidity. As a result of this, the ice and snow usually sublime and do not wet the soils.

On the basis of these characteristics, the conditions under which they develop, and their distribution, we may call these soils, high-mountain tundra soils.

High-mountain Soils of the Alpine Zone. As we know, the alpine zone lies between the snow line and the upper boundary of the forest. In the Tian Shan mountains the alpine zone is located approximately at an altitude of 2800 to 3500 m. (5) and in the Altai mountains at about 2400 to 3000 m. (2). The growing period in this zone lasts about four months; the rest of the time everything is covered with snow.

The dryness of the climate of the mountain regions of Northern Sinkiang, as mentioned above, has made a definite impression on the vegetation and soils of the alpine zone. Here there is none of the luxurious high-mountain meadow vegetation which is characteristic of similar zones in the Alps and the Caucasus. The plant cover of the alpine zone of Northern Sinkiang has xerophilic characteristics. According to the data of Lyu Zhen'-n"ao (3) the following species are abundant: *Erigeron pulchellus, Lagotis glauca, Gentiana algida* et *tenella, Papaver nudicaulis, Pedicularis cheilanthifolia, Saussurea involucrat, Seseli (Stenocoelium) athamanthoides, Saxifraga hirculus* and others.

In the alpine zone of the Altai grow mosses, sedges and grasses (*Pidium, Festuca, Agropyrum, Agrostis, Aeluropus, Carex*). Closer to the upper border of the forest, among the annuals, are found thorny and ericaceous undergrowth.

The soils of the corresponding zone of Tian Shan are characterized by a high humus content and a gray-brown color (5). In the upper part of the zone they are leached and nearer the tree line at a depth of 60 to 100 cm. They effervesce with hydrochloric acid and have an illuvial carbonate horizon.

In the alpine zone of the Altai, mountain-meadow and mountain meadow-steppe soils are distinguished (2). Mountain-meadow soils develop on the slopes of the northern exposure and are about 50 cm. thick. The upper horizons (0 to 30 cm.) are gray-brown, friable, and contain peat. Their pH is 5.7. Underneath them are skeletal clay loams. On the southern slopes the soils are not as thick. Their total peat layer is about 10 cm. The humus horizon is colored brown. The brown color of these soils is explained by incomplete decomposition of organic matter, and this distinguishes them from the deep black mountain-meadow soils of the Caucasus. It was the color of these soils which gave Ma Yun-chzhi the reason to call them brown mountain-meadow soils.

Soils of the Mountain-forest and Mountain-steppe Zones. The zone of mountain forests on the southern slopes of the Bogdoshan range is located at an altitude of 2000 to 3000 m.; on the northern slopes it is at 1800 to 2800 m. Ma Yun-chzhi (7) notes that from the lower border of the forest zone to 2200–2400 m. mixed forest grows, consisting of spruce, *Salex, Cineree, Sorbus, Betula* and others. Above this border there are pure stands of spruce (Picea abovata). All mountain-forest zones are characterized by thick grass cover, as represented by the following species: *Cladonia fimbriata, Carallochiea innata, Gentiana umbelluta, Hieracium umbellutum, Purola unflora* and others (3).

In the mountains of Altai the forest zone lies somewhat lower (1300 to 2400 m.), but also consists predominantly of spruce (2). The mountain-forest zones of the Tian Shan and the Altai do not represent a continuous belt, but rather widespread spots of forest, usually on the northern slopes of individual mountains and ravines and encountered very little on the southern and eastern slopes. The southern slopes are usually occupied by steppe vegetation with rare spots of bushes. Such an interrupted structure of the forest zone in the Tian Shan mountains is easily seen from an airplane over the region from Lake Bagrashkul to the town of Urumchi. According to visual estimation, on some mountain ranges the forest does not occupy more than 10 to 15% of the area. This peculiarity of the mountain forest zone has been noted many times by all those who have investigated Sinkiang (2, 3, 5, 7). In those areas where the forest occupies a narrow discontinuous belt or is lacking altogether, a gradual transition is noted from low-mountain desert-steppe vegetation to that of the high-mountain cold desert steppe. This is particularly characteristic of Kun'-lun, where the forest zone fades out completely on some tracts (sometimes of more than a thousand kilometers). This combination of forest and steppe has served as a basis on which some investigators (2) have designated this the forest-steppe mountain zone.

Two basic soil complexes are distinguished in the mountain-forest zone, corresponding to the type of plant cover: soils under forests, and soils under steppe vegetation.

In the upper parts of the mountain-forest zone the soils are leached of carbonates; in the lower parts of the zone under the steppe vegetation a morphologically pronounced illuvial horizon of carbonates is observed. In depressed portions of the relief along streams and rivers meadow soils are predominant. In the lower part of the forest zone south of the town of Tsitai at an altitude of 1800 m., we described two sections: one in a depression under a thinned spruce forest and meadow of mixed grasses (Sect. 5), the other on a southern slope under grasses and xerophilic shrubs (Sect. 6). Below the forest zone a narrow belt of chestnut soils extends, which we described as 0.3 km. from the lower border of the forest (Sect. 38). This belt is near Lake Sairam-Nur at an altitude of 1990 m. above sea level. The soils mentioned are characterized by a dark-brown color, except for the shrub dry-steppe soils which were a pale yellow color with a high humus content (Table 1). In the chestnut soils there was a fairly pronounced illuvial horizon of carbonates in the form of "beloglazkas"—characteristic circular accumulations of carbonates (Table 2, Sect. 38). In the corresponding horizon of Sect. 6, mealy friable concretions of carbonates are observed.

TABLE 1

Content of humus and carbonates in the soils of the mountain-forest zone

Depth of sample, cm.	Humus, %	CO_2, %	Depth of sample, cm.	Humus, %	CO_2, %
Meadow-chestnut leached soil, Section 5			Shrub, dry-steppe soil, Section 6		
0–15	15.00	0.40	0–10	5.45	1.15
15–35	3.56	0.52	10–30	1.56	6.64
35–50	1.78	0.42	30–50	0.81	7.15
50–70	4.82	0.39	50–70	0.43	5.01
70–80	2.11	0.69	—	—	—

TABLE 2

Chemical composition of dark chestnut soil (Dzhungaria, Sect. 38)

Depth of sample, cm.	Humus, %	CO_2, %	Total adsorbed cations in meq.	Solid residue, %	Total particles <0.01 mm., %
0–4	12.12	1.28	—	0.270	12.0
4–12	7.20	0.43	34.20	—	24.0
12–20	2.81	0.52	27.44	0.305	34.5
20–30	1.84	0.51	21.36	0.315	41.9
30–60	1.15	22.55	—	0.465	—
60–82	0.52	15.22	—	0.130	—
82–107	0.29	10.73	—	0.095	—

On the soil map of the USSR (1954) and in the adjoining regions around Lake Sairam-Nur chernozems are distinguished, and below the chernozems, chestnut soils. In this region the chernozem zone fades out and disappears completely, while the zone of chestnut soils occupies a narrow belt closely adjoining the forest zone.

In the mountain districts of the Altai, as in the Tian Shan, there is no clear boundary between the forest and steppe vegetation. Investigators from the Academy of Sciences of the Chinese People's Republic have established that in the upper part of the mountain-forest region of the Altai there are widespread spruce, deciduous trees and fir. Under these stands mountain gray forest soils with the following profile have developed:

A_0 0–14 cm. Forest litter of needles, interwoven roots of grasses and fungal mycelia; occasional inclusions of charcoal. Cinnamon-brown color; turning to dark gray with depth; pH, 5.5.

A_1 14–24 cm. Dark-brown grayish friable clay loam with gravel; pH, 6.

A_2 24–46 cm. Gray with brownish tinge, gravelly sandy loam with a platy structure; pH, 6.

AB 46–65 cm. Gray-brown clay loam with a platy structure; pH, 6.

B 65–100 cm. Red-brown-cinnamon with yellow clay spots; pH, 6.

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BC 100–140 cm. Yellow-brown structureless clay loam with coarse sand below.

On the southern, eastern, and western slopes under shrubs (*Spiria lossa, Done seria, Potentina flostecosa*) and grasses (*Acinia Alocinria*), and in the lower part of the zone *Artemisia*, mountain cinnamon-brown leached soils develop—which are similar to the cinnamon-brown forest soils—with the following profile structure:

0–14 cm. Dark brown coarse clay loam, cloddy structure; interwoven roots; no effervescence with HCl.

14–36 cm. Gray-brown clods of sandy loam with gravel; no effervescence.

36–56 cm. Brown gravelly clay loam with a lumpy structure; no effervescence.

56–90 cm. Dark yellow-brownish coarse clay loam; no effervescence.

In the lower part of the zone on northern slopes gray forest soils are widespread and mountain chernozems are found in spots, but on the soil map of the Altai they are not shown. On the southern slopes there has been development of chestnut soils with an illuvial horizon of carbonates below the 60 cm. depth.

Soils of the Desert Zone. Desert soils in north Sinkiang extend up to 1800–2000 m. above sea level and occupy the piedmont zone, the low mountains, and the entire Dzhungarian depression. According to the conditions under which the soils are formed and their basic properties, three soil groups are distinguished among the Dzhungarian desert soils: a) gray-brown; b) slight-brown or pale earth-colored; and c) brown desert soils.

a) The gray-brown desert soils occupy the zone of the Tian Shan and Altai piedmont. As a result of the dryness of the climate the plant cover here is thin and depressed and is represented by several species of halophytes and bushes. The parent material is composed of quaternary alluvial, alluvial-"proluvial"[2] and deluvial deposits, often salinized. Gray-brown soils have a gray-brown color and contain 1.4 to 2.5% humus. Their structure is platy-lamellar, as in sierozems. Going downward the color becomes lighter and goes over into a light yellowish-cinnamon-brown color of the parent material. In the lower horizons of the soils which developed on salt-containing parent material the color is darker, but the structure consists of clods. In nonsolonized types there is displayed slight leaching of the carbonates from the upper horizons (Table 3, sections 7 and 17).

TABLE 3

Content of humus and carbonates in desert soils of Dzhungaria

Type of soil, section no.	Depth of sample, cm.	Humus, %	CO_2, %	Total particles <0.01 mm., %
Gray-brown desert (Tian Shan piedmont); Sect. 7	0–10	2.53	0.97	—
	10–30	2.03	4.81	—
	30–50	1.05	5.58	—
Gray-brown desert strongly solonized (Tian Shan piedmont); Sect. 17	0–4	1.40	3.94	31.3
	4–8	0.97	5.03	39.8
	8–15	0.81	5.97	46.4
	15–25	0.75	4.77	—
	25–40	0.41	3.80	—
	40–70	0.26	4.40	36.3
Takyr (Dzhungarian plain) Sect. 25	0–3	0.47	3.09	59.8
	3–7	0.38	3.82	75.0
	7–20	0.39	5.13	98.0
	20–26	0.39	—	99.3
	26–50	0.31	4.65	96.5
	50–80	0.39	5.68	—
Brown desert strongly solonized (Dzhungarian plain); Sect. 21	0–5	0.66	2.79	—
	10–25	0.25	3.70	25.0
	25–50	0.29	3.65	23.3

In this zone cattle are raised chiefly. The dry-farm sowings are very small and irrigated agriculture is limited by the relief and insufficiency of irrigation water.

b) The light-brown desert soils occupy a narrow band in the alluvial fans of the mountain rivers and arroyos which are made up of clay loam-gravel deposits—gobis. Gobis are located between terminal ridges of the piedmont and the bands where the ground water tapers out. The soils of the gobi belt develop with very scanty atmospheric moisture and a deep water table under poor plant cover consisting of individual specimens of halophytic plants and scanty individual *Artemisia* shrubs. The upper horizons have a light straw-yellow color, a platy-lamellar structure, but sometimes a fine-porous spongy texture. They contain about 0.5% of humus in all, which hardly affects the color. For this reason these soils are called "light colored earths" ("svetlozem"). In the lower horizons below 10 to 20 and sometimes below 30 to 40 cm. there is a large amount of gypsum; the gypsum horizon is thick and can often be followed down to depths of two to three meters. Many scientists call these soils gypsiferous sierozems (2, 7).

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[2] "Proluvial" refers to detritus washed down a mountain and deposited at its foot.—Translator.

Below the belt of gobis, in contact with gravel and silty parent material of the sloping plain, extends the belt in which the ground water tapers out. In some spots the ground water emerges in the form of springs which, flowing together, form small collecting streams. Two reservoirs have been built for such water north of Urumchi. In this belt there are many agricultural oases and luxuriously developed plant cover, consisting predominantly of water-loving plants (*Tamarix, Phragmites communis, Alchagi, Stipa splendeus* and others). The soils here have developed under the influence of ground and surface water and are meadow-swamps, meadow soils and solonchaks.

c) On the other side of the belt in which the ground water tapers out and down to the sands of Dzosotyn-Elisun grow low *Holorachne soongarica* shrubs among which are found spots of saxaul and some species of annual halophytes. The water table in this part of Dzhungaria is at a depth of 15 to 17 m. Here, there are widespread desert brown solonized soils and bare spots of takyr. They both develop on the alluvial lamellar deposits.

TABLE 4

Content of adsorbed cations in the desert soils of Dzhungaria (Laboratory of the town of Urumchi, 1956)

Type of soil, section no.	Depth of sample, cm.	Ca^{++}	Mg^{++}	Na^{+}	Total	Ca^{++}	Mg^{++}	Na^{+}
		meq./100 gm. soil				as % of total		
Brown desert; Sect. 22	0–9	2.55	1.44	0.27	4.26	59.9	33.8	6.3
	9–25	1.85	1.76	0.04	3.65	50.7	48.2	1.1
Brown desert strongly solonized; Sect. 21	0–5	1.59	1.12	1.55	4.26	37.3	26.3	36.4
	10–25	4.03	0.70	1.50	6.23	64.7	11.2	24.1
Gray-brown desert strongly leached; Sect. 17	0–4	7.15	0.05	2.53	9.73	73.5	0.5	26.0
	4–8	6.70	2.19	1.90	10.79	62.1	20.3	17.6
Takyr; Sect. 25	0–3	2.70	0.23	10.07	13.00	20.8	1.8	77.4
	7–20	4.49	3.40	3.28	11.17	40.2	30.4	28.4

TABLE 5

Analysis of the water extract of takyr (Sinkiang, Laboratory of the town of Urumchi, 1956)

Type of soil	Depth of sample, cm.	Solid residue, %	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$	Ca^{++}	Mg^{++}
Takyr, Sect. 25	0–3	0.710	0.007	0.110	0.121	—	0.030	0.107
	3–7	2.370	none	0.031	0.667	0.881	0.337	0.037
	7–20	1.475	traces	0.037	0.718	0.326	0.075	0.018
	20–26	2.870	"	0.037	0.768	1.140	0.467	0.045
	26–50	1.195	0.007	0.041	0.516	0.385	0.025	0.012
	50–80	1.150	0.007	0.044	0.393	0.343	0.024	0.049

The brown desert soils cover a large area. They are characterized by a cinnamon to brown profile color and a high degree of solonization. Their upper horizons, down to 5 to 10 cm., have a flaky structure. Below, there are small compressed lumps and fissured horizons which gradually go over into a light straw-colored or brown parent material (Tables 3 and 4; sections 21 and 22).

Among the brown desert soils, as noted above, are found spots of takyr-like soils and takyrs. Dzhungarian takyrs are distnguished from those of Central Asia by an even greater lack of living things. Ephemeral grasses do grow in certain spots on Central Asia takyrs, but they do not grow at all on the plains of Dzhungaria. Not even algae are found here. The surfaces of the takyrs are dissected into polygonal plates, between which are preserved furrows with cracks into which clay has been deposited. The surfaces of the takyrs are sometimes covered by a very thin red-brown coating of clay colloids, lending a shiny gleam to the surface. The upper horizons have a fine-porous structure and decompose into structural separates which are elongated along the horizontal axis. The structure of the takyrs is very dense; they can be pierced with a spade only with difficulty; but because of their fine structure the walls of the soil section can easily be destroyed with a knife. The soils under description are strongly solonized and salinized (Table 5). Their solid residue varies from 0.71 to 2.87%, while the amount of adsorbed sodium reaches 18 me., which amounts to 30 to 77% of the total adsorbed cations (Table 4). Everywhere among the takyrs are found dead halophyte bushes and around them small mounds which are subject to washing away. The characteristics shown refer to the initial stages of formation of takyrs and to a radical difference between them and the takyrs of Central Asia.

The most widespread takyrs predominate in the belt adjoining the semi-permanent sand mounds of Dzosotyn-Elisun. The sand mounds adjoining the takyrs are covered with a solid crust 3 to 5 cm. thick formed as a result of transfer by wind of clayey scales and salts from the surface of the takyr. The clayey scales and salts cement the sandy particles together, creating a solonetz crust which keeps the surrounding sand dunes from blowing away, and holding back the present advance of the sands onto the plains portion of the Dzhungaria.

Conclusions

1. The mountain regions of Northern Sinkiang are in the zone of the deserts of Central and Middle Asia. As a result the dryness of the climate makes itself felt and the plant cover and soils develop with insufficient moisture.

2. In the high mountains above the snow line, high-mountain tundra soils develop.

3. In the alpine zone between the snow line and the edge of the forest, brown high-mountain meadow soils develop.

4. The mountain-forest zone in the Tian Shan and the Altai is combined with the steppe. The forest generally consists of spruce and is located in isolated spots on the northern slopes of mountain ravines and summits. The southern slopes are covered with mixed grassy vegetation. Under the forest cover, gray forest and peat podzolized soils with a cinnamon-brownish tinge develop. Under the steppe vegetation, cinnamon-brown leached and chestnut soils develop.

5. The desert piedmont of Dzhungaria is composed of gray-brown desert soils, which are replaced by light brown desert soils on the upper parts of the sloping plains. On the plains portion of the Dzhungaria brown desert soils have developed among which are found large islands of takyrs and takyr-like soils.

6. In the zone in which the ground water tapers out, on the floodplains of the Manas and Urumchi rivers, the soils are predominantly meadow, meadow-bog and bog soils and solonchaks.

7. The middle part of the Dzhungaria is composed of primitive soils on semi-permanent sands.

8. On the desert ranges of the eastern spurs of Tian Shan, up to an altitude of 2000 m., there is a preponderance of mountain stony-marly primitive soils.

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WARPING THE BOGS OF COLCHIS

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CONSIDERABLE attention was devoted to warping in planning the project for reclaiming the bogs of Colchis, along with other improvement measures, because conditions were favorable for its successful use in the Colchian lowland. It was decided, however, that as we lacked sufficient experience in warping, it would be best to develop warping on a relatively small area. The work would be of an experimental nature which would provide opportunity for research.

An experimental warping plot with an area of about 3250 hectares was taken from the vast swampy area directly adjacent to the town of Poti, where soil reclamation work had begun in 1925 and where, since 1928, studies had been carried on concerning the basic questions of warping. Particularly the following items were studied: a) subsoil conditions on the warping tract; b) the warping capacities of the Rion river; c) the working relations of the warping canals; d) the nature of alluvium deposition; the texture and chemical composition, as well as the hydrophysical properties of alluvium; e) compaction of the alluvium and deformation of the peaty subsoils; f) changes in the relief of the tract being warped and other processes accompanying warping; and g) hydrological conditions in the water intake and so on.

Natural Conditions in the Warping Tract

The tract on which warping was to be carried out was originally a peat bog in the form of a plain with a general slope from north to south and a pronounced hillock microrelief. In the eastern and western areas of the tract to be warped there were two protuberant domes of peat. Between these domes, and also between the belt along the river and the tract with the domes, there was a gully holding the channel of the swampy river Shavi-gele.

At the beginning, the soil cover of the tract being warped was represented by alluvial, bog, and intermediate waterlogged soil types. The greatest part of the tract was occupied by peaty soil and subsoil. The thickness of the young, slightly decomposed but strongly waterlogged peaty subsoil varied from 3 to 9 m. over the whole of the tract. Beneath this lies bog and alluvial-bog deposits 0.3 to 2.7 m. thick, while a a depth of 5.4 to 8.7 m. below sea level lies a compacted, completely mineralized, buried peat

The slightly elevated belt along the river was occupied by non-bog mixed forest interwoven with vines. Extending from this belt to the peat bog, on alluvial-bog and silt-bog soils there was an alder forest strongly interwoven with vines and constantly waterlogged. On the peat bog carex, cinquefoil, reeds, cat-tails and rushes had developed; on the domes, in addition to carex there were sphagnums and ferns. Young growths of alder were found in isolated groups all over the peat bog.

Source of the Warp

As the source of the warp we used the river Rion, which has a well-developed drainage area acted upon by various topographical, climatic, soil, plant, and geological conditions. The river has an abundance of water and is characterized by non-uniform hydrological conditions.

Frequent variations of the water level during the year are characteristic of the Rion river. The rise of the water level begins at the end of February and is related to the melting of snow in the drainage basin. The water level reaches a maximum in April and May. After May a certain decrease in the water level is noted, but as a result of rainstorms it still remains high. The water level falls slowly and hits the minimum mark only in September, October, and January, although in these months, too, there are sometimes cases of abrupt rise (Table 1).

The water level is closely related to the streamflow. According to data from Engineer K. V. Chelbin, the average value of the maximum streamflow of the Rion river at the village of Sakochakidze is 2150 m^3 per second; it varies from 1408 to 2663 m^3 per second (Table 2).

According to hydrometric data taken in a region near the tract (at the village of Sakochakidze), the Rion carries annually more than eleven billion cubic meters of water with an

TABLE 1

Water level in meters of the Rion river by months

Month	Water level			Difference
	Minimum	Maximum	Mean	
December	0.86	3.81	1.67	2.95
January	0.86	3.63	1.52	2.77
February	0.74	4.06	1.88	3.22
March	1.05	4.00	2.53	3.00
April	2.01	4.21	2.70	2.20
May	2.23	4.21	3.23	1.99
June	2.15	4.10	2.99	1.95
July	1.70	3.93	2.75	2.23
August	0.65	3.77	1.81	3.12
September	0.64	3.42	1.66	2.78
October	0.57	4.21	1.44	3.64
November	0.58	4.21	1.82	3.63
Annual	0.67	4.21	2.15	3.64

enormous amount of sediment (up to 10,760,000 metric tons; Table 3).

The Rion has a high relative turbidity over the course of the year, but in the spring-summer period, when there is a high rate of snow-thaw and rainfall, the siltation rate is especially high. Only in April does the load of sediment rise as high as 2,000,000 metric tons (Table 4).

A comparison of the water level and the turbidity shows that no close interrelation exists between them. Sometimes the turbidity is different at the same water levels. This failure of the water levels to correspond with the turbidity is natural since the formation of the sediment depends on many factors.

The results of particle-size analysis of the suspension of the Rion river shows that silt particles are predominant near the tract at the village of Patara-Poti (Table 5).

TABLE 2

Maximum streamflow in cubic meters per second in the Rion river at the village of Sakochakidze by years

	Years								
	1928	1929	1930	1931	1932	1933	1934	1935	mean
Maximum streamflow	2546	1408	2218	2663	1671	2554	1843	2360	2150

TABLE 3

Annual volume of flow, load of sediment, and average turbidity of the Rion river by years

Year	Volume of flow, m³	Load of sediment, metric tons	Average turbidity, gm./l.
1928	11,672,900,000	11,008,000	0.943
1929	9,521,700,000	7,017,000	0.737
1930	7,727,000,000	5,162,000	0.668
1931	12,960,000,000	12,889,000	0.993
1932	14,437,700,000	15,765,000	1.092
1933	12,481,700,000	12,720,000	1.020
Perennial mean	11,470,000,000	10,760,000	0.938

TABLE 4

Perennial average monthly sediment by months

Month	Sediment in metric tons	Month	Sediment in metric tons
December	450,500	June	1,402,000
January	348,500	July	1,096,000
February	636,600	August	487,400
March	1,028,000	September	481,500
April	2,049,000	October	492,700
May	1,762,000	November	528,700

TABLE 5

Particle-size analysis of suspension in percent

Average turbidity, gm./l.	Particle-size fractions in mm.					
	>0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001
1.77	2.84	17.15	21.46	19.20	14.30	25.05
2.90	0.14	7.45	31.40	21.07	24.13	15.81
3.89	0.52	8.64	39.77	21.22	25.15	14.72
4.20	0.43	7.07	44.15	17.74	20.98	11.23

History and Short Description of the Warping Project

The plan of the warping project was: 1) to bank the tract from the east, south and west; 2) to lead special canals from the source with a maximum flow rate of 160 cubic meters per second; 3) to provide regulating gates at the heads of canals and spillways in the banks on the water intake side. Thus the tract to be warped represented a water-collecting basin being filled with water rich in suspension and taken in from the Rion river through the warping canals. According to the plan the tract, after warping, was to consist of a surface inclined downward from the bank of the Rion river on the water intake side, with the index mark at the *banks* of the water intake canal 0.9 to 1.4 m. above the *mean* index mark of the water intake canal established by the drainage standard to agree with the index mark of the water level in the water intake canal.

By the beginning of 1928 all the work planned for the project had been completed. In February of the same year water from the Rion was directed into the warping tract, and it is actually this time which is considered to be the beginning of warping in Colchis.

As a result of the first observations it became clear that the project had not taken into account all the circumstances accompanying warping, so that changes had to be made in the hydrological installations and some were even eliminated. The method of warping was also changed. In order to expedite the process and increase the efficiency, the number of canals was increased. The period of warping established earlier, the volume of alluvium for the final warping of the tract, and so on, were not adequate.

Twelve more canals were constructed and connected into the network between 1933 and 1937. By the beginning of 1938, 17 canals were in use with an average interval of 300 to 400 m. between them.

Study of the warping processes established that the work of the warping canals was fully dependent on the hydrologic conditions in the Rion river. As a result of frequent floods the canals were operated almost continually throughout the year. Their action was especially effective in spring and summer (Table 6).

The minimum water level, and the one at which the canals could no longer be operated, were: Warping canal No. 1, 1.91 m.; No. 3, 1.46 m.; No. 4, 1.50 m.

The streamflow was also a definite function of the water level.

On the basis of seven years of observation, a maximum rate of flow per second was determined for the warping canals (Table 7). The maximum flow in the different canals was noted at different times. This was related to the condition of the canals, to their periodic cleaning, and to their readiness for taking in water from the source.

For a complete analysis of the useful effect of the warping canals we cite here data from Engineer K. V. Chelbin on the volume of flow, the load of sediment, and the turbidity (Table 8).

TABLE 6

Length of time of operating canals (in days) by months

Month	Canal No. 1			Canal No. 3			Canal No. 4		
	Max. water level, m.	Max. flow, m^3/sec	Days canal operated	Max. water level, m.	Max. flow, m^3/sec	Days Canal Operated	Max. water level, m.	Max. flow, m^3/sec	Days canal operated
December	4.09	37.20	8	4.15	78.00	10	3.50	31.30	8
January	3.46	17.33	3	2.98	14.00	4	2.55	6.60	3
February	3.90	30.32	6	3.47	32.80	9	3.30	25.00	9
March	3.94	31.60	16	3.54	36.80	22	3.24	23.40	20
April	3.95	32.10	23	3.07	44.40	28	3.98	56.00	27
May	4.00	33.80	26	3.67	44.40	30	4.17	71.60	29
June	4.11	37.90	25	3.73	48.00	27	3.68	38.20	26
July	4.00	33.80	21	3.69	45.40	25	3.48	29.40	23
August	3.76	25.80	12	3.68	43.00	13	3.41	26.80	12
September	3.78	26.60	8	3.45	31.60	9	3.34	24.20	8
October	4.01	34.30	7	3.70	45.90	7	3.42	27.00	7
November	4.24	42.60	7	3.88	56.40	8	3.53	31.20	7
For year	4.24	42.60	162	4.15	78.00	192	4.17	71.60	179

TABLE 7

Maximum flow in m^3 per second in the warping canals by months

Canal No.	Months											
	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	37.20	17.33	30.32	31.60	32.10	33.80	37.90	33.80	25.80	26.60	34.30	42.60
3	78.00	14.10	32.80	36.80	44.40	44.40	48.00	45.40	45.00	31.60	45.90	56.40
4	31.30	6.60	25.00	23.40.	56.00	71.60	38.20	29.40	26.80	24.20	27.00	31.00

TABLE 8

Volume of flow (m³ × 1000), load of sediment (metric tons), and turbidity (grams per liter) by warping canal and by year

Year	Hydrometric element	Canals							
		1	2	2a	3	3a	4	5	Total
1928	Volume of flow	136,581	16,839	—	107,395	—	63,400	—	324,215
	Load	325,961	18,179	—	179,202	—	112,619	—	635,961
	Turbidity	2.38	1.07	—	1.67	—	1.78	—	1.96
1929	Volume of flow	108,665	53,257	—	134,509	—	78,132	—	374,363
	Load	236,650	110,177	—	299,627	—	162,527	—	808,981
	Turbidity	2.18	2.07	—	2.23	—	2.07	—	2.16
1930	Volume of flow	73,924	39,709	—	52,972	—	30,948	—	197,553
	Load	181,768	70,546	—	93,087	—	58,159	—	403,972
	Turbidity	2.45	1.78	—	1.76	—	1.89	—	2.05
1931	Volume of flow	155,192	—	—	117,599	—	56,704	—	329,495
	Load	351,199	—	—	183,660	—	98,159	—	633,018
	Turbidity	2.26	—	—	1.56	—	1.73	—	1.92
1932	Volume of flow	294,054	143,839	—	234,126	—	155,978	—	827,997
	Load	791,839	295,479	—	478,855	—	310,841	—	1,877,014
	Turbidity	2.69	2.05	—	2.04	—	1.99	—	2.27
1933	Volume of flow	222,290	78,028	—	144,029	—	89,839	87,860	622,046
	Load	597,084	142,672	—	259,468	—	160,998	198,383	1,358,606
	Turbidity	2.68	1.83	—	1.85	—	1.79	2.26	2.19
1934	Volume of flow	117,703	75,686	48,946	154,587	47,416	130,853	65,059	640,250
	Load	231,578	162,527	135,346	266,622	101,036	279,409	127,150	1,303,668
	Turbidity	1.96	2.15	2.77	1.72	2.14	2.13	1.96	2.03
Total	Volume of flow	1,108,409	407,358	48,946	945,217	47,416	605,854	152,219	3,315,919
	Load	2,716,079	799,580	135,346	1,760,521	101,036	1,183,124	325,533	7,021,219
	Turbidity	2.45	1.96	1.77	1.87	2.14	1.96	2.12	2.12

From data in Table 9 we see that in different years the same canal delivered different quantities of water. This is explained by the hydrologic conditions in the Rion river and by the condition of the canals themselves.

According to the hydrometric data and to our approximate calculations, during the entire warping period beginning in 1928, the warping canals delivered about 15 billion m³ of water. At an average turbidity of 2.12 grams per liter, this enormous volume of water delivered about 32,000,000 metric tons of silt. When large floods took place the water poured onto the warping tract as a result of the river overflowing its banks. It has been calculated that about 6,000,000 metric tons of silt came in with this diversionary water during the warping period. A part of the sediment, suspended for long periods of time because of its extraordinarily great dispersion, did not deposit and was carried away from the tract with the drainage water. Its quantity was determined to be around 1,600,000 metric tons at a relative turbidity of 0.104 grams per liter. Taking this part of the sediment into consideration, it can be assumed that more than 36,000,000 metric tons of silt were deposited on the warping tract altogether.

TABLE 9

Mean values of the physical properties of warp and its carbonate content

Texture type	Hygroscopic moisture, %	Natural moisture, %	Carbonate content, %	Volume weight	Specific gravity	Porosity, %
Sand	2.05	43.10	10.22	1.27	2.67	52.55
Sandy loam	2.65	47.17	10.06	1.13	2.67	57.65
Coarse clay loam	3.10	54.87	9.16	1.05	2.70	60.93
Medium clay loam	3.59	67.20	8.92	0.83	2.75	69.90
Fine clay loam	4.10	72.60	8.70	0.86	2.77	69.00
Clay	4.55	75.60	—	0.83	2.67	69.20

Deposition of the suspended material on the warping tract took place at the moment the water arrived there. Considering the abrupt fall in the velocity of the water current in the canals, most of the sediment (having larger particles) deposited near the canals, while the fraction with the smaller particles moved farther on. As a result of the deposition of clayey material, and, to a smaller degree, of the warping, the area between the canals at the beginning was pervious only with difficulty. The southern and southwestern parts of the tract were very slightly warped because the water reaching this far contained mostly highly dispersed material. The greater part of the sediment was deposited along the warping canals and the channel of the Shavi-gele river, as was expected. In general the thickness of the deposits of warp increased from the channel of the Rion river to the valley of the Shavi-gele river, in places exceeding 4 meters. But once past the water intake, it gradually decreased.

The deposited warp was also non-uniform in its texture. In some places, because of a high rate of warping, the alluvium was characterized by a coarse texture and by complex layer formation with depth. At greater distances from the canals, chiefly fine clay loams and clayey material with a uniform profile were deposited.

At the beginning of deposition the sediments of warp were saturated with water, but with the course of time they gradually became free of it and as a result became more compact.

In a study of the process of compaction on the warp deposits the following was found:

1) Compaction of the entire mass of the warp takes place unevenly. If the mass is uniform in texture the degree of compaction depends on the age of the deposit. Quicker and greater compaction of the surface layer occurs than that of the lower layers. If the mass has varying particle sizes, then the layer with the coarser texture becomes more densely compacted.

2) The time of compaction of the warp depends on texture. Alluvium with fine texture, giving a low yield of water, undergoes compaction over a considerably longer period of time than does alluvium with coarse texture.

3) The compaction of warp, especially in the lower layers, proceeds very slowly over an extremely long period.

Along with compaction of the warp, settling of the underlying peaty subsoil takes place as a result of pressure from the warp. The underlying peaty subsoil can contract to a third of the total thickness of the peat, and a considerable volume of alluvium goes toward filling in this settling. This explains why it is not possible to notice an increase in the level of the surface of the land at first, regardless of the deposition of warp.

Regardless of the fact that the amount of alluvium deposited is three times as great as what was intended by the project, warping of the tract has not yet been completed. Such a difference between the actual deposits and those originally planned was caused chiefly by this unforeseen compaction of peaty subsoil under pressure from the deposited warp.

On the basis of field and laboratory research the following types of warp have been distinguished: sand, sandy loam, coarse clay loam, medium clay loam, fine clay loam, and clays. Those present in warp in the smallest quantities are sand and sandy loam. They deposit chiefly in the immediate vicinity of the canals in the form of separate thin lenticular deposits. More widespread were the coarse clay loams; they usually deposited in places close to canals among other textural types. The medium clay loams were encountered chiefly in thick deposits, but the fine clay loams and clays were found at considerable distances from the canals and in the southern part of the tract. In places where the warping was not complete, the clays and fine clay loams were waterlogged and strongly gleyed.

Generally the warp deposits of all thicknesses had a stratified structure. Individual layers were distinguished by their texture; all combinations were possible depending on the character of the layer formation. Often, in places, the entire thickness would consist of four or five layers of different texture in which layers of the same textural profile would be repeated. Because of this variation in textural profile of the warp deposits, it was necessary to compile a map of each half-meter layer, taking into account intermediate layers not less than 25 cm. thick.

Two main types of warp deposits were distinguished according to their profiles: a) deposits of warp with a simple, uniform profile; and b) those with a complex, stratified profile. In the first type are warp deposits having layers of uniform texture: sand and sandy loams, coarse clay loams, medium clay loams, fine clay loams, and clays. The second type combines varied deposits with different textures in each of its several layers. For instance, in the top one-meter thickness seven basic types are found: 1) coarse clay loams; 2) medium clay loams; 3) fine clay loams and clays; 4) coarse clay loams on clays; 5) medium clay loams on coarse clay loams; 6) medium clay loams on fine clay loams and clays; and 7) clays and fine clay loams on peat.

For a complete analysis of the warp deposits, we give the average values of the physical properties, carbonate content, moisture, and so on. (Table 9).

All textures of warp deposits contain a high proportion of carbonates and a fair amount of phosphorus and potassium. The carbonate content varies from 1.63 to 11.40%, while in the clayey types the carbonate content is smaller. The content of P_2O_5 varies from 0.11 to 0.29%, K_2O from 1.51 to 2.28%, humus from 1.11 to 3.05%.

Warping is a radical process which in a short time can make radical changes in the appearance of the soil cover and in the whole landscape of the tract being warped. The stagnation of the water, the deposition of thick masses of sediment, and the duration of these processes caused sharp changes in the previously existing conditions on the warping plot. This was indicated by changes in the plant cover. Because the root systems were buried at great depths, the native forest which existed in a swampy belt along the banks of the Rion river completely died out. It consisted of alder, ash, elm, beech, maple and other tree species. While the warp was still semifluid the dominant plants in the tall forest were replaced by reeds. After partial compaction of the warp, willows appeared and the reeds began to disappear as a result of the disappearance of conditions essential for them. Consequently, only willows grew on the parts where warping was almost complete.

After warping had been completed on the northern part of the tract, alder and Caucasian wing nut (*Pterocarya fraxinifolia* Lam.) developed in the thick willow forest. Alder then became the dominant form, and now in the well-developed alder forest only single examples of willow are encountered. Elm and ash have already appeared, and, in places, vines have developed—wall pellitory, sturdy greenbrier, blackberry and ivy. Grassy vegetation is poorly developed in the forest because of the shade. In some places grass is entirely lacking. It develops more or less where sunlight penetrates through the forest canopy. Here the most widespread plants are Solomon's seal (*Polygonum hydropiper,* L.) and the slender panic grass (*Oplismenus undilatifolius* [Ard.] P. B.).

Peat-forming grassy plants are abundant on non-forested tracts. They are characteristic of alluvial soils along rivers—sweet clover, "sukhunka" (*Paspalum digitaria*), "rosichka" (a weed grass), barn grass, slender panic grass, and others. Vegetation established itself in a very short time. From the beginning of warping to the present, the botanical composition of the plant cover underwent radical changes. The most stable plant cover proved to be in the places where warping was complete.

Owing to warping, completely new soils with different properties were formed compared to those existing before warping..

Conclusions

1. Warping is the cheapest and most reliable method of reclaiming bogs.
2. The effectiveness of warping depends on the hydrologic relations of the source and the method of warping, on the number and functional status of the warping canals, and on the soil and subsoil conditions of the tract.
3. The greatest effectiveness was shown by the continuous method of warping using all floods with the result that more water and warp were applied.
4. Acceleration and direction of the warping processes were proved to be possible.
5. Warping improves the sanitary condition of the locality. Plant and soil cover changes radically and abruptly.

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WATER RELATIONS OF CLAY LOAMS ON FOREST PLANTATIONS IN THE STEPPE AND FOREST-STEPPE

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Some idea of the water relations of soils under forest and large forest plantations has already been given for sandy soils by the first brief investigations of P. A. Kostychev and A. Vermishev, by those of A. A. Izmail'skii for the oak groves of the Poltava area, by those of G. Ya. Bliznin for the widely known Black Forest[1] and of S. F. Khramov for Veliko-Anadol.

More profound research into the water relations of soils and subsoils in the Veliko-Anadol was carried out by G. N. Vysotskii. On the basis of this work and data from G. F. Morozov and P. V. Ototskii, Vysotskii formulated the doctrine of forest influences. Later he and his students P. K. Fal'kovskii, V. I. Akopov and others studied the water relations of the soils of forest-steppe oak groves which, together with data obtained in Veliko-Anadol, was put into general form in his well-known book "The Hydrological and Meteorological Effect of Forests".

During Vysotskii's lifetime and under his influence, a broad study of soil and subsoil moisture was begun by the VNIILKhM (Vsesoyuznyi nauchno-issledovatel'skii institut lesnogo khozyaistva i mekhanizatsiya, the All-Union Scientific Research Institute for Forest Economy and Mechanization), VNIALMI (Vsesoyuznyi nauchno-issledovatel'skii agrolesomeliorativnyi institut, All-Union Scientific Research Institute for Land and Forest Reclamation), UkrNIILKhA (Ukrainskii nauchno-issledovatel'skii institut lesnogo khozyaistva i agrolesomelioratsii, the Ukrainian Scientific Research Institute of Forest Economy and Land and Forest Reclamation), BelNIILKh (Belorusski nauchno-issledovatel'skii institut lesnogo khozyaistva, the White Russian Scientific Research Institute of Forest Economy) and others. After World War II, questions of the water relations of soils and subsoils under forest plantations were taken up thoroughly and at length by the Soil Institute, Academy of Sciences, USSR and by the Institutes of Forestry, Academy of Sciences, USSR, and of the Ukrainian and White Russian SSRs. Also by the UkrNIILKhA and other organizations.

Figure 1 shows the areas at which studies were made of the water relations of sandy loam soils and subsoils under forest plantations in the steppe and forest-steppe. It includes almost all portions of the European area of the USSR.

The result was the discovery of unique characteristics of the soil water relations in different natural zones and their dependence on the forest type and the age and density of planting. It is to be regretted that the primary data was so little published and was not treated by a uniform method. For the value of unavailable water to plants some investigators accepted 1.3 times the maximum hygroscopicity, others 1.5 times and a third group took the moisture of the permanent wilting point. Some authors in their work took only the moisture per unit volume of soil and did not give the volume weight of the soils and subsoils, thus making it impossible to recalculate these data by another method. It was therefore difficult and sometimes impossible to state the information in general form. For this reason, when we compiled a survey of the water relations of the soils in different subzones of the steppe and forest-steppe zones, we were able to use only a part of the published material after recalculating it in uniform basis. As a basis we used the results of our research (1948 to 1953) on southern chernozems (down to a depth of 5 m.) under large-scale and strip forest plantations at the Vladimirov Land and Forest Reclamation Experiment Station in Nikolayev region. We also used the results of observations by Ya. K. Zarudnyi, I. I. Prokopenko, V. I. Slovikoskii and others under the direction of Academician P. S. Pogrebnyak in the Black Forest (1946 to 1951, Kirovograd region, southern margin of the forest-steppe), under 21-year-old forest plantings and natural oak groves on podzolized cherno-

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[1] In the Ukraine about 55 km. north of Kirovograd—Transl.

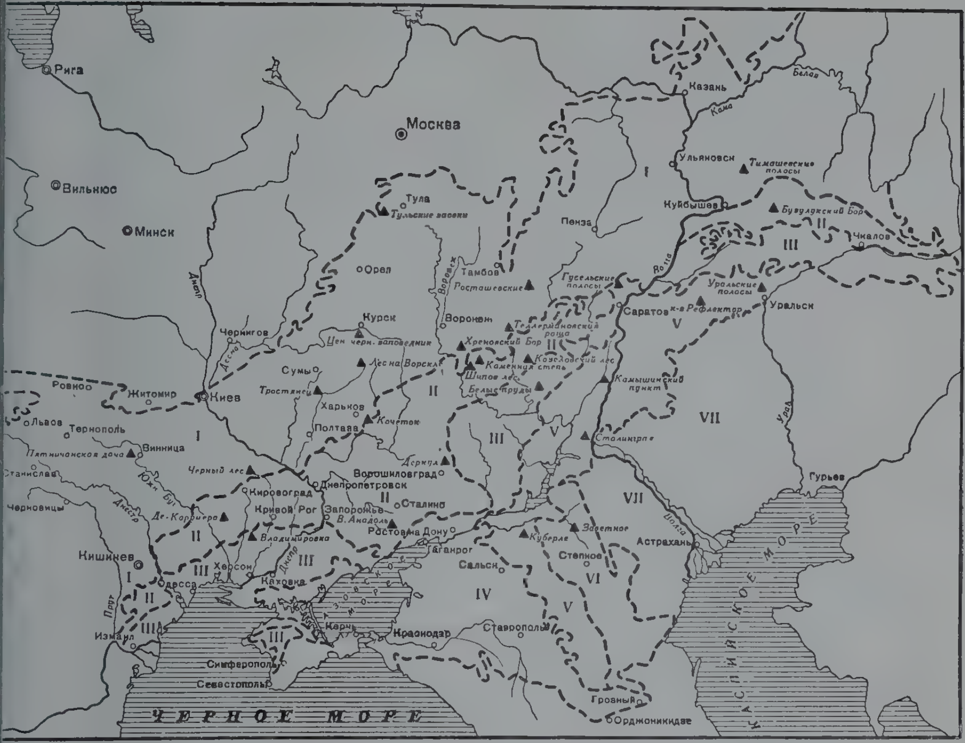

Fig. 1—Map of the location of areas at which investigations of soil moisture are being carried out. I—forest steppe; II—ordinary chernozem; III—southern chernozems; IV—Caucasus foreland chernozem; V—dark-chestnut soils; VI—light-chestnut soils; VII—Zone of the semi-desert.

zems, dark-gray and light-gray forest soils on steep slopes, and on peat-podzolic gley soils at the bottoms of hollows. In addition, we used data from Bol'shakov (5)[2], Pogrebnyak, Skorodumov et al. (10), Fal'kovskii (15), Zonn (8, 9), Afanas'yeva, Karandina et al. (2, 4), Skorodumov (15), and Serebryakova (13).

Table 1 shows the results of the principal research on large-scale artificial plantings and natural forests outside the influence of the forest margin on clay loams or clays, mostly silty soils.

The greatest depth to which the soil becomes wetted is noted in the dark-gray forest soils of Trostyanets, the least in the southern chernozems of the Vladimirov Forestry Tract, where the snow cover is thin and brief. There is fairly deep wetting of the southern chernozems in the eastern steppe zone (Derkul, Kozlovskii Forest, Belyie prudy) where the snow cover is thicker and lasts longer.

The depth of wetting varies in different years, like the weather. The minimum values are 1.8 to 2.6 times as small as the maxima and sometimes even 3.2 times as small. The peat-podzolic gley soil on the bottoms of hollows in the Black Forest is sometimes wetted only to a depth of 35 cm. because of its poor physical properties, in spite of the fact that it receives surface runoff and that the water table is not deep. Plantations here should be classified with the moist oak stands, since the ground water is usable. The example given shows how variable the water relations can be under actual natural conditions. In general there is greater wetting

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[2] The bibliography shows only a part of the basic and subsequent papers used in the preparation of this article.

TABLE 1

Water relations in forest topsoils and subsoils[a]

Geographic location	Kind of soil	Forest plantation		Depth of saturation, cm.	Accumulation of water in 2 meter layer, mm.	Amount of available water in 2 m. layer						Loss of spring moisture supply, %			Summer precipitation, mm.	Total loss of moisture from 2 meter layer of soil, mm.			Participation of spring moisture supply in total loss, %		
						Spring			Fall												
		Composition	Age			Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.		Min.	Max.	Av.	Min.	Max.	Av.
Kursk Reservation	Thick chernozem	Oak	35 40	—	284	372	489	431	135	242	172	136	348	256	255	424	612	511	27	61	50
Black Forest	Leached chernozem	Oak	21	160	236	348	509	400	124	168	146	201	341	255	213	382	615	468	39	67	54
Same	Podzolized chernozem	Birch, ash	50–70	170	242	273	541	399	92	177	133	126	364	266	213	288	638	479	43	70	54
Same	Dark-gray forest	Oak, hornbeam	34	148	210	275	516	372	130	150	143	145	366	229	213	307	640	442	33	67	51
Same	Light-gray forest	Oak, ash	180–70	146	226	299	436	363	110	134	123	173	302	240	213	342	576	453	44	63	53
Same	Peat-podzolic gley	Aspen, boxelder	50	—	223	379	525	453	171	281	215	187	330	243	230	370	604	473	37	59	51
Trostyanets	Dark-gray forest	Oak, ash, boxelder	50	299	219	411	455	436	135	392	210	61	287	218	—	—	—	—	—	—	—
Tellerman	Same	Oak	220	—	—	356	449	414	—	242	242	139	226	176	143	279	339	319	40	71	56
Kozlovsk forest	Ordinary chernozem	Oak, boxelder	50–55	160	197	172	272	215	10	31	18	153	258	194	103	265	355	297	48	95	66
Same	Same	Same	same	206	167	149	280	211	10	95	38	109	254	163	103	239	292	266	37	94	61
Derkul	Same	Oak, ash	50	200	237	163	317	265	0	13	4	209	226	217	165	313	452	382	50	66	58
Beliye prudy	Southern chernozem	Oak, boxelder	30	170	197	195	287	240	—	—	—	127	226	179	99	222	312	278	51	88	67
Same	Same	Ash	44	—	180	235	320	278	—	—	—	91	273	191	99	234	359	290	31	86	65
Vladimirov Forestry Tract	Same	Oak, birch	31	69	164	163	319	226	32	55	42	132	168	155	165	254	410	320	40	66	50
Kamyshin	Dark-chestnut	Oak	24	—	—	—	—	—	—	—	—	98	289	211	70	115	417	281	69	85	77
Same	Same	Boxelder	45	—	—	106	449	287	—	—	—	68	250	179	85	91	350	264	61	75	70

[a] The reliability of the average data is not great because of the short periods of observation.

of the soil by precipitation in the forest-steppe and the eastern part of the steppe than in the western part.

The accumulation of water in the fall-winter-spring period in the top two meters of the soil and subsoil decreases from the forest-steppe to the steppe. It is 50 to 70 mm. greater in the Black Forest than in the Vladimirov Forestry Tract. A considerable accumulation of water in the soil is observed at Derkul. In dry years the accumulation of water in the forest-steppe is sometimes 8 to 12 times as small as in years with a large amount of precipitation. If a comparison is made of the accumulation of water in a layer of soil greater than two meters, the difference between the dry and wet years becomes even more abrupt. Only in the Kursk reservation is the accumulation of water in the soil always greater because of the runoff of surface water from higher-lying fields. On the steppe such great differences in the accumulation of moisture in the soil in the fall-winter-spring period are not seen in wet and dry years.

In determining the available water in the soils we took as the lower limit of available water to be 1.3 times the maximum hygroscopic coefficient and in some cases the moisture at wilting which, in general, is close to the amount of unavailable water to plants. Data for comparison with this were recalculated from various sources.

In the forest-steppe in spring, the amount of water available to plants in the top two-meter layer of soil and sub-soil is considerably higher (363 to 436 mm.) than in the steppe (211 to 287 mm.). Thus, in the soil of the Black Forest this amount of water was 40 to 75 mm. greater than in that of the Vladimirov Forestry Tract. Only in occasional moist years does the supply of available water in the steppe reach values which are noted on the forest-steppe in dry years. In moist years the supply of available water in the top two-meter layer of the soil and subsoil is not more than twice as great as that in dry years.

Thus, for the accumulation of available water in the soil a pattern appears which differs from that of the accumulation of moisture in the cold, more variable portion of the year. This is evidently because in the fall of moist years, the remainder of the available water is preserved in the soil; thus the storage is greater in spring and fluctuations in different years are reduced. By fall, in the soil and subsoil on the forest-steppe, much more unused but available water remains (123 to 242 mm.) than on the steppe (4 to 42 mm.). For this reason, in the forest-steppe even when there is comparatively little precipitation in the cold portion of the year, the spring saturation of the soil is deeper and the storage of available moisture to plants in spring is greater.

It often happens on the steppe that by fall no available water is left in the top two meters of soil and subsoil, not only in dry years but even in years when the first half of the summer is wet.

In steppe and forest-steppe soils under forest plantations there is always an impervious horizon with a low, slightly varying moisture. In the southern chernozems of the Vladimirov Forestry Tract under large-scale plantation, the upper border of this horizon (that is, the layer with a wilting moisture content of 14% and below) lies at an average depth in spring of 309 cm., but in the fall it is at a depth of 15 to 40 cm. In years with a greater amount of precipitation, the moisture content of the impervious horizon in spring may increase somewhat, but even in these years this horizon remains drier than those above and below it. In spring on the podzolized chernozem and dark-gray soil of the Black Forest, the upper boundary of the impervious horizon is not much deeper (average depth 305 to 346 cm.) while in the light-gray forest soils it is even closer to the surface (255 cm.). In contrast to the southern chernozem of the Vladimirov Forestry Tract it comes only slightly nearer the surface in fall. In the dark-gray forest soils of Trostyanets, this boundary lies at a depth of about 3 m.

It seems to us that the association between the upper boundary of the impervious horizon and a definite depth (about 3 m.) under different climatic conditions is not just a coincidence. It is possible that this association is connected with temperature conditions in the subsoil and with the movement of water in vapor form upward from below in the cold portion of the year.

The impervious horizon in the southern chernozem of the Vladimirov Forestry Tract is not thick (in spring up to 120 cm., in fall from 240 to 410 cm.); in the dark-gray soil of Trostyanets, according to Fal'kovskii's data (15), it is 7.2 m. (evidently in the fall). The low thickness of the impervious horizon in the Vladimirov

Forestry Tract is evidently related to the flatness of the area, the relatively superficial water table (8 to 10 m.) and the absence of sandy interlayers make possible the very slow movement downward of film water to the impervious horizon (12). This is more probable since the capillary rise in the loess-like clay loam of the Vladimirov Forestry Tract supposedly reaches 225 to 375 cm. and the gap between the capillary fringe and the impervious horizon amounts to a total of 200 to 450 cm.; the moisture of this horizon is close to the minimum moisture capacity.

The Trostyanets area is thoroughly drained by deep hollows and gullies which, in depressed areas, go even into the forest, so that the ground water here is at a depth of 40 to 60 m. and cannot exert any material influence on the impervious horizon.

The moisture of the impervious horizon in the Black Forest (absolute value, 8 to 10% relative value, 35 to 43%) is less than that in the Vladimirov Forestry Tract (11 to 13% and 50 to 59%, respectively). In the Trostyanets area the impervious horizon has a higher moisture content (12.5 to 14%) and considerably greater thickness than in the Vladimirov Forestry Tract. Evidently the thick root system of the oak stand dries out the subsoil more thoroughly than can the less developed root system of the oak plantations of the steppe. The water relations of the topsoils and subsoils of the steppe under large forest plantations and of the forest-steppe under oak stands should be included with the impervious (unpercolated) type. In Trostyanets even in the wettest years the depth of wetting did not exceed 4 m., while in the Black Forest at the southern margin of the forest-steppe it was 225 cm. The periodically percolated type of water relations in the topsoils and subsoils of the forest-steppe is observed only at the edge of the forest. For southern chernozems, even at the edge of the forest, the nonpercolated type of water relations is characteristic. In this respect the southern forest-steppe is more like the steppe than like the forest zone.

For the forest of the Kursk Reservation the soil and subsoil water relations are characteristically periodically percolated, since they receive the surface runoff from higher-lying fields. In the northern part of the forest-steppe the water relations of the soils and subsoils may also have that character, but we have not found published data in this field.

The total water loss from the soil during the growing period is mostly loss from water stored in the spring and from precipitation reaching the soil in the summer. This calculation is true only if no observation has been made of runoff or influx of surface or soil water from the side of the movement of moisture from the root layer of the soil to a lower, remote layer of the subsoil or of the movement of water in any form upward from below. Under field conditions this calculation is permissible only for soils of almost level areas which have adequate permeability but which are not, in spring, saturated with water down to the water table (which is at a depth where it is inaccessible to the roots). On forest plantations where forest litter is present and there is good permeability of the soil, such a calculation may also be used for slopes where there is no surface or subsurface runoff.

Calculation of the loss of water from the soil may be carried out for layers of any thickness, but it is desirable to include the entire thickness accessible to the roots (not less than 2 m. or, on the forest-steppe, 4 m.): this makes it possible to establish the total loss of water from the topsoil and subsoil. Different authors calculate differently the total loss of water from soils under forest plantations, natural steppe vegetation and crops. This means primarily that many investigators take their precipitation data during the growing season from the nearest field weather station. They include the same values for effective precipitation in the total water loss from soils under forest plantations and under farm fields. They do not consider the different retention of precipitation by different types of vegetation or rainfall of less than 10 mm. per ten days; or, they consider 60% of the summer rainfall (3).

Bol'shakov and Gertsyk (5) also took 60% of the summer rainfall as the effective precipitation and paid no attention to the different retention of precipitation by the crowns of trees and the steppe vegetation. Later, Bol'shakov (6) took into consideration as much as 80% of the summer precipitation.

The most correct method for calculating the total water loss from soils under forest plantations is to include the precipitation measured directly beneath the canopy of the trees (7, 14), and to measure on fields all the precipitation which falls. Popov (11) implies that effective precipitation means that part of the precipitation which may be used by plants through their root systems. "However," he writes, "even those small quantities of precipitation which fall only on the surface of the soil and on plants and quickly evaporate into the atmosphere cannot be recognized as completely useless to plants, since, in any case, they lower the temperature of the uppermost soil layer and the temperature of the plants themselves. This may be of great importance for the plants, and in some cases the precipitation may cause retention of moisture in the upper layer of the soil." The ratio of the effective to the total precipitation was called by Popov the coefficient of effective precipitation. For Odessa, on the steppe, it is 0.20, while for Mleyev, on the forest-steppe on fall-plowed fallow, it is 0.25. For early spring crops it is 0.30. Alpat'yev (1) considers that fundamentally the agricultural evaluation of summer precipitation can be subjected to the following criteria: the soil-moistening effect of precipitation, the range of moistening or drying out of the upper layer of the soil, and the biological effect of the precipitation. In the steppe zone the upper level of the root system of crops is 3 to 5 cm. deep. The moisture lost in wetting this layer is considered by Alpat'yev to be ineffective. By "range of moistening" he implies the difference in stored moisture not yet assimilated by the roots of the layer from the time of precipitation to the moment when the next precipitation begins. On the steppe the range of ineffective precipitation amounts to 6.2 mm. (2.8 to 8.8), while the percentage of this which takes part in the water balance of the crops amounts to 30 to 35%.

In calculating the water loss from the soil we consider it impossible to exclude "ineffective" precipitation which moistens the upper 3 to 5 cm. of the soil, since it causes vigorous biological processes in the top soil horizon. This is very important even when the processes take place only briefly, as in the southern Ukraine. It is necessary to moisten the upper layer of the soil so that water can reach the lower horizons. Then nutrients can be washed down from the upper horizon to make possible an exchange of air between the soil and the atmosphere and a number of other processes in the soil. To this must be added the fact that plants are capable of absorbing a certain quantity of moisture through the surfaces of the leaves. The moisture evaporating from the surface of the soil increases the absolute and relative moisture of the air. This decreases the transpiration and acts favorably on plants. The moist air just above the surface of the soil stops further evaporation from the soil surface. For this reason we recalculated the data of Afanas'yeva and Bol'shakov (up to 1956), excluding only 20% of the precipitation.

Forest soil, shaded by the canopies of trees and protected by the forest litter, uses precipitation from its surface and even that in the litter more effectively than does the soil of fields, even though the forest soil does not receive a certain quantity of the precipitation intercepted by the canopies of the trees. A different role is played by that part of the precipitation intercepted by grasses in the forest and the crops. Evaporating in the immediate vicinity of the soil and moistening the layer of air above the soil, this moisture causes a kind of transitional layer between the soil and atmospheric moisture.

The total loss of water from the soil is most often determined according to the greatest storage of water in the spring and the least storage of it in the fall. Here, the loss of water from the soil in early spring or late fall is not considered, because the intake of water is usually greater than the loss.

Let us turn to Table 1 and consider the elements of moisture loss by forest plantations on different tracts of the forest-steppe and steppe zone. The loss of the spring storage of moisture from the top two-meter layer of the topsoil and subsoil is, in general, greater on forest-steppe than on the steppe. However, on the steppe the moisture loss from the soil in wet years and in some cases even intermediate values of moisture losses are close to the average moisture loss in the forest-steppe. Under prolonged observation, a great difference emerges in the loss of the spring storage of moisture from the soil in different years (in Trostyanets the maximum was 4.7 times the minimum). With respect to the large loss of the spring storage of moisture and the considerable amount of precipitation, the total loss of moisture during the growing period is greater on the forest-steppe than on the steppe. In some years the total loss of soil moisture varied by 1.6 to 2.2 times and sometimes even by 4 times (Kamyshin). The participation of the spring storage of moisture in the total loss from the top two-meter layer of the topsoil and subsoil in the forest is always a little more than 50%. On the eastern part of the steppe it is still higher (61 to 77%) as a result of the greater thickness and persistence of the snow cover.

It must be considered that the total loss of moisture by farmland will exceed the total loss of water from the soil by the amount of precipitation retained by the vegetation. In order to determine which type of vegetation causes the greatest increase in the soil moisture cycle, consideration must be given to the amount not only of water which accumulates in spring, but also of the total loss of water during the growing season, including the precipitation reaching the soil surface. If it is necessary to determine the role of the different crops in the moisture cycle of the atmosphere, then a comparison is made of the total losses of water by farmland, the destination of the total moisture lost from the entire layer of the topsoil and subsoil which is accessible to the roots, and the interception by the vegetation. There is usually a parallel relation between the two types of total losses of water.

In establishing the total loss of water by farmland, consideration of the moisture cycle must not be restricted only to the top two-meter layer, but must encompass the entire thickness of the soil in which the movement o water takes place. However, our data and tha from the literature allow us to make a comparison only for a four-meter layer which completely encompasses the root zone and either fully o partially encompasses the impervious horizons known to be characterized by moisture conten which changes only slightly.

Primarily, it is the loss of moisture from th subsoil at depths of 2 to 4 m. which should b considered (Table 2). This loss varies widely according to weather conditions in differen years. There are some years when the storag of moisture between 2 and 4 m. not only does not decrease by fall but even increases. The average loss from the deep horizons of the subsoil does not exceed 35 mm., often decreasing to as low as 6 mm., while in the Vladimirov Forestry Tract there is an average increase in the moisture content of the impervious horizon after the spring-summer-fall period. Finally, the data from Derkul, covering a period of one year, cannot be used to characterize average conditions. The maximum values of the moisture loss from the deep layers of the subsoil are observed in years with a dry growing period; they reach 50 to 70 mm. and sometimes even 140 to 181 mm. The greatest intake of water by the deep layers of the subsoil during the growing period is 20 to 40 mm., sometimes

TABLE 2

Loss of water by forest, in millimeters

Geographic location	Kind of soil	Character of forest plantation	Loss of spring storage of moisture from layer 2 to 4 m. depth			Total loss					
						From layer 2 meters depth			By farmland		
			Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
Vladimirov Forestry Tract	Southern chernozem	Artificial, large scale	+58	27	+7	254	410	320	290	432	355
Derkul	Ordinary chernozem	Same			81			452			594
Kozlovsk Forest	Same	Same	+28	70	6	265	355	297	265	378	329
Same	Same	Same	+21	140	33	239	292	266	246	411	325
Kursk Reservation	Thick chernozem	Natural forest	+66	156	63	424	612	511	528	776	640
Trostyanets	Dark-gray forest	Same	+40	181	33				436	641	563
Black Forest	Leached chernozem	Artificial, large scale	+30	51	13	382	615	468	405	654	534
Same	Podzolized chernozem	Natural forest	12	59	35	288	638	479	388	719	568
Same	Dark-gray forest	Same	+69	28	+4	307	640	442	369	640	491
Same	Light-gray forest	Same	+10	16	7	341	576	453	400	660	513

eaching 58 to 69 mm. The total loss of moisure by a forest is greater than the total loss of moisture from the top two-meter layer of the oil not only by the amount of interception by he crowns but also by the amount of water which increases or decreases in deep horizons of the subsoil.

If we disregard the single year of data for Derkul, it is fully evident that there is a coniderably greater loss of water (by 150 to 200 mm.) by the forest in the forest-steppe than hat of the steppe, since the oak stands of the orest-steppe are usually not under site class II n quality, while the oak plantations of the teppe (excluding lowlands) are not above site lass III in quality.

Conclusions

1. The moisture cycle in the topsoils and suboils under forest plantations in the forest-steppe s considerably greater than on the steppe, that s, both the intake and loss of moisture from the oil in the former zone are greater than in the atter.

2. The moisture cycle in the atmosphere in orested areas of the forest-steppe is 150 to 200 mm. greater than that of the steppe.

3. An insufficient supply of water to the soil auses lower productivity of oak plantations on he steppe than of oak stands in the foresteppe.

4. In the steppe area the moisture cycle in he soil under forest plantations decreases from ordinary chernozem to dark-chestnut soils, but here are a number of exceptions.

5. The water relations of the topsoils and suboils under large-scale forest plantations and oak tands of the southern part of the forest-steppe hould be included among those of the nonpercolated type.

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PROFESSOR E. W. HILGARD (1833-1916)

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THE year 1958 marks the 125th anniversary of the birth of the eminent American scientist, E. W. Hilgard, professor at the University of California, and founder and first director of the California Agricultural Experimental Station. Hilgard's name is known to every soil scientist and agronomist. His memory is deeply honored by the scientific agricultural circles of various countries. He taught many generations of American soil scientists and agronomists and was a fellow of the National Academy of Sciences in Washington. Even in 1912, during Hilgard's lifetime, a bust of him was installed in the Agricultural College of the University of California in Berkeley with funds collected by students and faculty of the College. For many years the California Agricultural Station has issued a series of studies developing the scientific legacy of this scholar under the general title of "Hilgardia."

E. W. Hilgard completed his university studies in 1853 at Heidelberg. By 1855 he was working as a geologist in the state of Mississippi. In 1857 he was engaged in the study of geology of soils, and also of the agriculture of the state of Mississippi, which served as the turning point in his conversion into a soil scientist.

From Hilgard's pen have come hundreds of scientific works and papers published over the 60 years of his activity. Of these the principal ones are "The Influence of Climate on the Formation and Composition of Soils" (10), "Nature, Value and Utilization of Alkali Lands and Tolerance of Crops for Alkali" (11) and the general monograph, "Soils; Their Formation, Properties, Composition and Relations to Climate and Plant Growth in the Humid and Arid Regions" (12). Works by Hilgard appeared continuously from 1878 to 1898 in "Forschungen auf dem Gebiete der Agrikulturphysik" published by Wolni in the reports and bulletins of the California Experimental Station, and in other scientific journals of America and Germany. Translations and reviews of his work were published in the Russian "Journal of Experimental Agronomy." The translation of the work "Nature, Value and Utilization of Alkali Lands" was accompanied by the editorial comment: "We present the translation of Hilgard's paper almost without abridgement of any kind, having in view the ever-increasing interest among us in solonetz soils and also the extreme poverty of the Russian literature on this problem (3)."

The works of Hilgard, like the works of Dokuchayev and Sibirtsez, played an indispensable part in the theoretical foundation of modern soil science and scientific agronomy, leaving a deep historical imprint in the science.

In research on the role of climate in soil formation (10), Hilgard attached preeminent importance to the influence of temperature and moisture. Later, in his monograph "Soils" (12) he also noted the influence of rock composition on the fertility of the soils formed from them and the role of topography. He particularly emphasized the significance of plants in soil formation. "The formation of a soil," wrote Hilgard, "begins from the moment of the settling of lower plants on the surface of rocks, first of lichens, later of mosses and ferns; the action of plants is accompanied by the action of innumerable bacteria and molds." However, he attributed the leading role in soil formation to climate.

He divided all soils into two basic groups according to their moisture content: soils of humid regions and soils of arid regions. A group of transitional soils was also separated. On this foundation Hilgard composed a summary table of the average data on the chemical composition of the soils of the different groups, based on the results of analyses of 696 soils from humid regions, 573 soils from arid regions, and 178 transitional soils. In the soils of arid regions Hilgard noted the predominance of physical weathering, slight formation of clay and humus, and the slight role of leaching processes. All of this leads to the fact that soils of arid regions, according to Hilgard, are always distinguished by sandiness and siltiness, low humus content, and high electrolyte content. In soils of humid regions, where, according to Hilgard, chemical weathering is of predominant significance, a markedly higher content of silica and aluminum oxide soluble in acids and sodium carbonate was noted. He considered humus only as a product of the decomposition of plant residues under the influence of microorganisms; the humus content depends on the content of those substances from which the humus was formed.

Hilgard distinguished saline soils and soils of the tropical zone. He also divided soils of the tropics into three groups according to type of humidification. Hilgard considered it necessary to give different practical recommendations for the tillage, fertilization, and reclamation of soils of different regions and groups. To his monograph were appended practical suggestions on methods of field investigations of soils and on the selection of soil samples, and he described methods of chemical analysis.

Hilgard devoted much attention to the composition and condition of the plant cover as an indicator of soil fertility. One of Hilgard's first papers on the soils of the Mississippi basin was devoted to this problem. He studied the ash content of the plants.

Hilgard preferred to describe soils in vertical section and as early as 1860 he was close to an understanding of the processes of eluviation and accumulation of iron compounds. This process he called "lixiviation"—eluviation—a concept which has been kept to the present day in the literature on weathering and soil formation (verbal communication, H. Jenny, 1957).

Hilgard dealt almost not at all with questions of soil classification. He considered it possible to classify soils only according to the type of deposition of parent material as residual, colluvial, alluvial, and eolian. In a special report on the classification of soils at the International Agrogeological Conference in 1911, Hilgard and Loughridge (13) noted the difficulty and prematurity of compiling a general classification of soils and considered that, for the time being, only the compilation of a regional classification was feasible. For compiling a table of soils it was necessary, in their opinion, to take into account the totality of such factors as climatic conditions, chemical and physical properties of soils, lithology and type of formation of deposits, soil color, and type of vegetation. Hilgard and Loughridge pointed to the necessity of calculating the properties not only of the upper humus layer, but also of the subsoils, giving attention to the physical properties. However, they stressed that individual physical or chemical properties cannot serve as the basis for a classification of soils. A genuine scientific classification must present a many-sided characterization of soils which will also reflect their usefulness and value for agriculture. Hilgard and Loughridge thought that the principal goal of the International Agrogeologic Conference of 1911 was the establishment of uniform acceptable methods of soil research (physical, chemical, biological) through the adaptation of an absolutely definite uniform terminology. These recommendations, of course, are just as significant today.

Russian soil scientists and agronomists knew and valued the works of Hilgard. V. V. Dokuchayev and N. M. Sibirtsev mentioned his name in their lectures. Sibirtsev repeatedly noted (5–8) that Hilgard and his school in soil science had many general features and scientific beliefs which were analogous to those of Dokuchayevian soil science in Russia. However, he wrote: "... what is one-sided, incomplete, and vague in the case of Ramann, Hilgard, and other western scientists was thoroughly developed far earlier in Russia, from the conceptual and factual standpoint, in the classification of Dokuchayev." (7).

Glinka, in his book "Soil Science" (4) often alludes to the opinion of Hilgard on various questions. Glinka attached great importance to Hilgard's ideas on the role of the moisture of the climate in soil formation. But he considered that, "Hilgard's analyses with respect to the soils of North America do not contribute anything essential to a notion of the process of soil formation, since it was the superficial horizons, for the most part, which were analyzed" (4).

The progressive ideas of Russian genetic soil science influenced both Hilgard and his students. Kellogg (15) wrote in 1957 that, because of the "language barrier," the brilliant school of soil science which developed in Russia around 1870 under the leadership of V. V. Dokuchayev did not become fully known in Western Europe and America until 1914, through the book of K. D. Glinka. Hilgard strove to study and utilize the Russian scientific literature. In his monograph and other publications the names of Kostychev, Kossovich, Vinogradskiy, Vil'yams, Ototzkiy, Middendorf, Shmidt, Rudzinskiy, and Mazurenko are mentioned, with references to their works. Hilgard was acquainted with the classificational and genetic works of Dokuchayev and Sibirtsev. He corresponded with P. S. Kossovich, received samples of chernozems from him and analyzed them, publishing the results of the analyses. He conversed extensively with Russian soil scientists who visited him during this period (Tulaykov, 9).

The well-known Hungarian soil scientist, Sigmond (16), wrote of Hilgard: "He was not only an outstanding student of soils, but also a first-class analyst, who pointed out the inadequacies and inaccuracies of the methods prevailing at the time and eliminated the existing analytical errors. It was he who called the attention of other investigators to the importance in soil science of determination of the insoluble residue, of soluble silica, of the ratio of SiO_2 to Al_2O, and the CaO and Na_2O content . . ."

Hilgard worked out his own method of preparing a hydrochloric acid extract and proposed a method for the separation of mobile silicic acid by using a concentrated solution of sodium carbonate (instead of the 5% solution recommended by other soil investigators). Attaching great importance to chemical methods in soil research, Hilgard studied the need for the microscopic investigation of samples for determining the composition of the insoluble residue. Besides chemical methods of study, determining the potential reserves of nutritional substances in soils, he recommended the carrying out of field plot experiments with a number of controls for estimating the productivity of soils directly in the field.

In 1873 Hilgard built and described an apparatus for particle size analysis of soils. Hilgard's apparatus, like the earlier apparatus of Schöne, was based on the hydraulic elutriation of soil particles by a current of water, directed upward from below. The rate of water flow varied from 0.25 to 32 mm. per sec.; each rate corresponded to a definite particle size. Even though this apparatus was not perfected, as Vil'yams (1), Sibirtsev (8), and Glinka (4) note, it was widely used, along with Schöne's apparatus, in the last quarter of the 19th century.

A large part of Hilgard's scientific activity was devoted to the study of salted soils, their origin, properties, and reclamation. His publications in this area are classic (K. D. Glinka and K. K. Gedroits referred to them) and had a great influence on the scientific development of this problem, although some of his views have now become obsolete.

According to Hilgard, the source of the salts is the weathering of rock. The nature of the transfer of salts occurring during weathering depends on the climatic conditions of the region. In humid regions, easily soluble salts are leached out by atmospheric precipitation into the ground water and are then carried out by subterranean currents and by rivers into lakes, seas, and oceans. Compounds which are not easily soluble in water, among them nutrients, are leached to only a slight extent even in humid regions; they are adsorbed and held firmly by the soils. In arid regions almost all the salts produced during weathering remain in the soil.

Hilgard almost wholly excluded the possibility of horizontal movement of salt solutions in arid regions, considering that it occurred only over negligible distances from high ground to the foot of slopes. He also recognized the existence of this process in cases of ground water cropping out. The vertical movement of salts in the profile occurs (according to Hilgard) by means of water solutions within the upper 4 to 5 feet (he compared these measurements to the height of maximum wetting).

Salted soils were considered by Hilgard to be the result of the aridity of the climate (precipitation less than 500 mm. per year), of slight leaching of the salts formed during weathering, and of increased evaporation, all of which result in accumulation of salts at the surface of the soil. The possibility of intensive evaporation of moisture was limited to a five foot layer (approximately 1.5 m.). The occurrence of salts at a depth exceeding 1.5 m. was considered safe for plants. Salt contents in saline soils were limited to only such elements as were contained in rocks before the beginning of weathering and soil formation. Hilgard even emphasized that salts cannot enter soil in indefinitely large amounts from the subsurface waters. Therefore, the ground water, its relations and mineralization, were not included by Hilgard among the factors responsible for salt accumlation in soils. This underestimation of the role of mineralized ground water was perfectly intelligible for that era and for that stage of soil science and reclamation. It was not until some decades later that Soviet soil science produced a developmental theory of salinization of soils and their reclamation on the basis of an exhaustive appraisal of the geochemical role of the ground water and the phenomena of migration and accumulation of salts.

Hilgard established the preponderant accumulation in salted soils of NaCl, Na_2SO_4, Na_2CO_3, and also the frequent occurrence of $CaSO_4 \cdot H_2O$. The presence in the soils of some regions of $MgSO_4$, $MgCl_2$, and $CaCl_2$ he attributed to their being leached out of adjacent deposits impregnated with these salts. Soils containing preponderantly NaCl and Na_2SO_4 Hilgard called "white alkali". Soils with a preponderance of Na_2CO_3 in the salt composition were related to "black alkali" soil. He noted that "white alkali" was usually also rich in nitrates, and that in "black alkali" phosphates are present in significant amounts. This subdivision of salted soils has been retained in the English literature even up to this day. Only in recent times has departure from this nomenclature been contemplated.

The nutrient contents in salted soils are, according to Hilgard, extremely important, provided they are not completely leached. The lowered fertility of salted lands is explained by the accumulation of an excessive amount of easily-soluble salts in the surface layer. The harmful action of the salts is manifested in damage to the root collars and root systems of plants, and also in the deteriorated quality of agricultural production (reduction in the suga content of the juice of grapes, reduction of th starch content in the potato). If salts are removed from soils or even if they are leached t a depth of more than 1.5 m. the soils becom extremely fertile, according to Hilgard, and d not even require the addition of fertilizer. Bu he also noted cases where, after the removal o salts, a soil proved to be infertile, so that agr cultural plants died in it. He did not explai the causes of this phenomenon. He did not a yet know about solonetz phenomena and did no attach importance to adsorbed sodium, believin that the Na ion cannot be firmly retained b soils, in contradistinction to K, Ca, and Mg ions However, Hilgard indicated the possibility o the transformations of "white alkali" to "blac alkali" (that is, of solonchaks to solonetzes when the soils received excessive moisture durin irrigation. Only the work of Gedroits in th USSR, of Sigmond in Hungary, and of Wiegne in Switzerland gave rise to the theoretical concept of solonetz phenomena developing durin the salinization of solonchak soils.

Hilgard established the relative toxicity o salts for plants (Na_2SO_4:NaCl:Na_2CO_3 = 1:2:5), and also worked out the qualitative indices of the salt tolerance of plants. Moreover he emphasized that the tolerance of the sam plants to the same salts may differ dependin on the texture of the soils (in clay soils it i less than in sandy soils) and on the age of plant (young plants are less tolerant to salts). Man soil scientists, in particular Kelley (14), refe even now to the findings on the salt toleranc of plants obtained by Hilgard in a joint wor with Loughridge (11). The extreme toxicit of sodium carbonate for plants was explaine not only by the damage it does to the plant directly, but also by changes in the physica properties of the soils under the influence o sodium carbonate (compaction and dispersion) which causes deterioration of the water penetration and makes tillage of the soil difficult.

The formation of sodium carbonate, accordin to Hilgard, comes about through the interactio of calcium carbonate and highly soluble sodiu salts (principally Na_2SO_4 and to a lesser degre NaCl). A necessary condition for the occurrenc of this reaction in soils is the presence of carbonic acid, the formation of which is possibl because of the decomposition of the organi matter and activity of the roots of plants chiefly in the deep horizons of soil with insufficient oxygen. Contributing to the latter is excessive soil moisture. The nearer the surface, the greater the access to air; the carbonic acid content decreases, and sodium carbonate formation does not take place. According to Hilgard this explains the preponderant deposition of sodium carbonate at a certain depth in the soils, but not at the surface.

Hilgard's practical recommendations on the control of salinization and the reclamation of saline soils were based wholly on his theoretical concepts. In the opinion of Gedroits (2), Hilgard was the first to approach the problem of solonchak reclamation scientifically. Inasmuch as the basic cause of salt transfer from the deep horizons of the soil to the surface (where salts cause the greatest damage) is considered to be evaporation from the soil surface, the basic method of controlling salinity is considered to be the reduction of evaporation in every possible way. To this end mulching is recommended, as well as shading of the surface and maintenance of the top layer of the soil in a mellow condition during the summer period. Hilgard also attached importance to the transpiration of plants. Thus he thought that the role of alfalfa in reclamation consists not only in shading the surface, but also in the increased evaporation of moisture from the deep horizons of the soil via the root system of alfalfa, owing to its deep rooting, which permits the retention of the salt at a depth greater than 1.5 m. He includes alfalfa among the most salt-tolerant crops—it tolerates a soil salinity of 0.4% (average in a 1.2 m. layer), while other crops grow poorly at a salinity of only 0.2 to 0.3%.

Believing that the storage of salts in soil is limited and that their lateral movement is impossible, Hilgard recommended for control of salinity, the sweeping off or raking up of salt on the surface. He also recommended special cultivation of salt-tolerant plants, with a view to their ultimate extermination, or sowing salt-tolerant grasses for pastures. These ineffective measures for controlling soil salinity, owing to Hilgard's great authority, were later recommended repeatedly both in the English (Kelley) and the Russian (Vilenskiy, Bushinskiy) literature.

The assertion that salts migrate only within the upper 1.5 m. of the soil and that intensive evaporation of moisture is possible only at depths not exceeding 1.5 m. led to the recommendation that salts be leached out to this depth and also that drains be constructed at this depth. The draining of salted soils was deemed an extremely desirable, although not obligatory, measure, since it accelerates the action of other reclamation procedures (irrigation and application of gypsum) and increases the success of reclamation in general. Drainage was regarded not only as a means of removing excess water during irrigation and percolation, but chiefly as a means of removing salts. Tubular closed drains were also considered a measure contributing to the retention of moisture required by plants (by preventing the runoff of water from the surface and providing a more mellow soil structure above the drains).

Emphasizing the necessity for a differential approach to the reclamation of different soils, Hilgard recommended, for soils salinized mainly with NaCl and Na_2SO_4, irrigation, leaching, and drainage. In the case of sodium carbonate salinization, the most important measure must be the application of gypsum, combined with irrigation and drainage. It was recommended that the quantity of gypsum be calculated according to the amount of sodium carbonate in the soil. Deeming the secure retention of sodium ions in the soil impossible, Hilgard naturally did not take into consideration the importance and amount of exchangeable Na^+. Only Gedroits proved the necessity of removing exchangeable Na^+ by means of applying gypsum to solonetz.

For the irrigation of easily permeable sandy soils, Hilgard considered it necessary to use not only fresh water, but also salt water. Moreover, it was suggested that the amount of salt water required for irrigation should be increased significantly (as compared with the amount of fresh water), so as to leach out the salts more rapidly and not give them the opportunity of rising quickly to the surface. In determining the possibility of employing salt water for irrigation, Hilgard deemed it necessary to consider not only the overall amount and composition of the salts in the water, but also the type of soil to be irrigated and the amount of water required for irrigation. He set the limit for the salt content of the water which can be employed for irrigation in the conditions obtained in the U.S.A. at 1.2 to 1.7 grams per liter, noting, moreover, that in Egypt and the Sahara considerably saltier waters are used, having a content of about 3 to 4 grams per liter. As a result of studies in recent years we know that the safe utilization of mineralized waters for such irrigation is possible only with the leaching type of irrigation, where there is a good natural or artificial drainage.

Attributing great importance to irrigation and draining, Hilgard noted that these measures demand the cooperation of many farmers, that to make the country flourish, a secure peace and the progressive development of scientific and technical advances are necessary. He considered the cause of the barrenness of once-flourishing regions of ancient irrigation to be continuous warfare and destruction. Hilgard foresaw that the advancement of methods of land tillage and also the universal spread of irrigation and drainage in arid regions would lead to a significant increase in the productive area of the whole world, owing to the utilization of the salted areas of wastelands.

His devotion to peace and to the progress of science and technology is in accord with the modern tendencies of all progressive humanity to peaceful construction and control of the forces of nature.

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Methods

USE OF THE CHROMATOGRAPHIC METHOD IN STUDYING HUMIC SUBSTANCES OF THE SOIL

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THE complex and unique nature of the humic substances of the soil makes it necessary to study them not only by the methods of organic analysis, but also by physical and physicochemical methods.

Such methods as x-ray analysis of structure, infrared spectroscopy, the determination of optical density and so forth have helped to reveal some general principles of the structure of particle (molecule) of humic substances and also their specific peculiarities in different soils. This work is reviewed in an article by Kononova (7).

However, there is much in this subject which is still not clear, and the investigators are confronted with the problem of searching out new ways and means to advance the study of the nature of humic substances and their role in soil processes.

Chromatography is an exceptionally promising method, widely used in different fields of biology for studying plant substances, hormones, vitamins, antibiotics and various products of the life processes of organisms (9). Until now this method has been little used in soil science, especially in the study of organic substances.

The chromatographic method isolates in unchanged form, from complex mixtures, substances which are chemically very similar. The method was first suggested by the famous Russian botanist Tswett (12). In his study of chlorophyll Tswett used organic and inorganic adsorbents ($CaCO_3$, sugar, inulin). In subsequent work he used solvents (petroleum ether, alcohol, benzene and carbon disulfide) to isolate a number of pigments, and to show the complex nature and heterogeneity of this component of the plant organism which fulfills a very important purpose in photosynthesis. On the basis of experimental data accumulated in the chromatography of carotenoids, a number of regular patterns were established showing that the adsorption of carotenoids depends on their structure (18).

In soil science, Hock (15) was first to use the chromatographic method, studying with it the humic substances of different soils. By putting solutions of humic substances extracted from soils by the use of NaOH, NaF, $Na_2C_2O_4$ and Na_2HPO_4 through a glass tube filled with adsorbent (a specially prepared powder of aluminum oxide) and then examining the column in ultraviolet light with a wave length of 366 $m\mu$, Hock detected zones which fluoresced differently and provided evidence of the heterogeneity of these humic substances. He also observed a similar picture in chromatographing solutions of the hematomelanic, humic and fulvic acids of the soils (chernozem, podzol, brown forest and other soils). Hock concluded that the humic substances represented a mixture of separate particles or groups of chemical substances and that the typical characteristics inherent in the humic substances of one kind of soil or another are determined by the ratios of these components. Thus, the humic substances of chernozem contain not only complex particles characteristic of this soil, but also a certain proportion of less complex particles characteristic of podzolic soils.

Using adsorption chromatography on hydrated aluminum oxide, Tsintsadze (13) also observed the division of humic substances into zones, showing their heterogeneity; the adsorption here was irreversible.

A similar conclusion regarding the organic substances extracted from peat with 96% ethyl alcohol was reached by Trojanowski (17) who used chromatography on MgO columns. When he eluted the column containing organic substances with a 1:7.5 solution of oleic acid in alcohol, using then luminescent analysis, he noted the formation of several zones which were clearly distinguishable in ultraviolet light.

A different method of chromatography was used by Forsyth (14), Dragunov (3) and Khan (11), studying complex mixtures of organic substances extracted from soils with various solvents. These substances were adsorbed on activated charcoal and then individual fractions were eluted with water and organic and inorganic solvents.

An interesting method of ion exchange chromatography on cationic SBS was used by Drozdova (4) in studying the nature of fulvic acids. By this means she succeeded in showing the presence of quinonoid components in fulvic acids.

The method of paper chromatography has proved to be very promising in the study of forms of nitrogen in the humic substances of various soils. The detection of amino acids in humic and fulvic acids is evidence of the protein nature of a part of the nitrogen in both these groups (see the article by Kononova and Aleksandrova [8] for literature and experimental data).

This survey of the literature shows that the selection of one or more methods of chromatography in each case depends on the actual problem confronting the investigator.

In setting up the present work, the authors started with the idea of the heterogeneity of humic soil substances which are complex systems of high-molecular compounds; of the pattern of change in their characteristics and properties in different soils as determined by soil formation conditions; of the existence of a genetic connection between the basic groups of humic substances, the humic and fulvic acids.

Having the general structural traits of molecules (the presence of an aromatic nucleus and side chains of linearly polymerized carbon), humic and fulvic acids of different soils constitute a kind of single chain. A change in the nature and properties of individual members of the humic substances is determined by the ratio in their molecules of aliphatic and aromatic structures, by the size of the molecules and by certain differences in chemical structure (appropriate data from the literature and from experiments will be found in the articles b Tyurin [10] and Kononova [6, 7]).

The authors of this article assume that th chromatographic method amplifies certain a pects of the ideas presented heretofore. Tw methods of chromatography were tried—o starch and on aluminum oxide—in the beli that the reactions of these adsorbents with th solutions of humic substances could be differen Preliminary research established that the resul of chromatographing humic substances coul with strict observance of the experimental con ditions, be reproduced. Therefore, the presen article gives the methods which we develope

Preparing Samples of Humic Substances for Chromatographing

The subjects of investigation were humic acid extracted from ordinary chernozem (Kamen naya Steppe, Voronezh region) and humic an fulvic acids of peat-podzolic soil Dolgoprudnay Experiment Station, Moscow region). Humi substances were extracted from the previousl decalcified soil by several treatments with 0. N NaOH solution. The alkaline extract wa carefully filtered through a No. 4 suction filte and the humic acids were precipitated as a ge on acidification. To decrease the mineral con tent and free the gel from impurities, the latte was dissolved in 0.1 N NaOH; the solution wa equilibrated four to six weeks to allow the sus pended mineral particles to settle and then i was filtered through a No. 4 suction filter an a Chamberland filter. In the solution obtaine the humic acids were again precipitated by 0. N HCl. The gel of humic acids was washe first by decanting in beakers and then by di alysis in cellophane bags until disappearance o the reaction for Cl ion.

The acid solution containing the fulvic acid (after precipitation of the humic acids from th alkaline extract) was run through activate charcoal, on which the fulvic acids were re tained. Then, with small quantities of 0.2 N NaOH solution the fulvic acids were eluted fron the charcoal, the alkaline solution was neutral ized and concentrated to a small volume in a vacuum at 40° to 45° C., dialyzed in cellophan bags and subjected to electrodialysis at 80 t 100 volts until there was a negative reactio for OH ions. The dialyzed solution of fulvi acids was again concentrated in a vacuum an dried in air, forming a thin layer in a Petri dish. The dry preparation of fulvic acids obtained was carefully ground down to a powder.

The definite concentration of humic substances in the working solution is an important condition for successful chromatographing. It was established in preliminary trials that the best separation of the humic acids of chernozem into bands takes place at concentrations of 1.2 to 1.5 grams per liter; for the humic acids of peat-podzolic soil the optimum concentration was 2 to 2.5 grams per liter; and with fulvic acids the division into bands was observed only at a concentration of 10 grams per liter (calculated for the absolutely dry ash-free substance).

Preparation of the working solutions of humic acids was as follows: The dialyzed gel was added to distilled water. The suspension was carefully mixed and a determination made of the concentration of absolutely dry ash-free substance by evaporating a sample in a platinum beaker to air-dry consistency. This was followed by thorough drying of the deposit to constant weight at 105° and ashing in a muffle furnace. After this the suspension was diluted to the calculated concentration with 0.1 N $NaHCO_3$ solution, bringing the humic acid into solution in the form of sodium humate.

In the case of fulvic acids, the solution for chromatographing was prepared by dissolving the dry material in the required quantity of 0.1 N $NaHCO_3$ solution with allowance made for ash and moisture. It was also established that the best division of humic substances into zones on a starch column took place when the pH of the working solution was about 10 to 11. When the pH values were as low as 7 to 8, division into bands was not observed and at pH 9 it was not clear. Strongly alkaline solutions with a pH greater than 12 acted on the starch and gave a distorted picture. In working with Al_2O_3 columns there was better division of humic substances into bands within the wide range of pH 8 to 12.

On the basis of this, the pH of the solutions of sodium humates and fulvates prepared for chromatography was measured with a glass electrode on an LP-5 potentiometer and the pH was brought to the required value by carefully adding concentrated NaOH solution a drop at a time. The concentration of the humic substances remained practically unchanged by this addition.

Preparation of the Starch and Al_2O_3 Columns

Table grade potato starch was washed a number of times with distilled water, first by decanting in beakers and then on Büchner funnels. The starch was then air-dried at room temperature and sieved through a 0.25 mm. mesh. Preliminary investigation established that supplementary washing of the starch with water-saturated n-butyl alcohol was of no particular advantage in chromatographing humic substances.

The aluminum oxide was prepared as follows: The powdered aluminum oxide (pure, anhydrous) from the Stalin State Union Chemical Reagent Plant, series 36, 1956 was allowed to stand for four months in a solution of CaO prepared by diluting a saturated solution five times with distilled water. After standing, the Al_2O_3 was washed several times with distilled water, first by decanting and then on Büchner funnels, dried in marble beakers at 105° and then ignited in a muffle furnace at red heat.

For the preparation of the chromatographic column we used a glass tube the lower rim of which was drawn out; the length of the broad part of the tube was 8 cm. and its internal diameter 0.8 cm. When the chromatography was accompanied by luminescent analysis a quartz glass tube was used. The tubes were filled with starch or Al_2O_3 prepared as described previously and used for this in the form of a thick brei in suspension in distilled water. The technique of filling the tube was as follows: In the lower part of the tube above the drawn out lower rim was placed a loose pad of cotton forming a layer not more than 1 cm. thick, and then the suspension of starch or Al_2O_3 was quickly poured in at the top of the tube. The tube was allowed to stand until the liquid had completely flowed out; for starch this took 30 to 40 minutes, for Al_2O_3, ten to 15 minutes. The clearest division into bands of the humic substances took place on starch columns prepared 18 to 24 hours before the beginning of chromatography.

After the liquid had flowed off, the top of the column of starch or Al_2O_3 was then about 1 cm. below the upper rim of the tube. The solution of humic substances under investigation was carefully placed, drop by drop, with a pipette into the upper part of the tube above the adsorbent without stirring up the latter. The best results from the separation of humic substances into bands using tubes of this size were obtained by chromatographing 0.3 ml. of the solution of humic substances on the starch column or 0.5 to 1.0 ml. on the Al_2O_3 column. Passage of the solution through the column and the formation of bands took 1 to 1½ hours for starch and 10 to 15 minutes for Al_2O_3. The chromatography was accompanied by luminescent analysis using 366 mμ ultraviolet light.

Results of Chromatographing: Starch Columns

The results of chromatographing humic substances of different soils on starch columns were varied. A picture of the chromatograms is shown in Figure 1: 1, 2 and 3 are the columns seen in daylight, 4, 5 and 6 in ultraviolet light.

In the experiment using the humic acid of the chernozem (column 3), with chromatography of 0.3 ml. of a solution containing 0.45 mg. of absolutely dry, ash-free substance, we observed the formation of three bands: The upper one, colored brown, was fairly wide (6 to 8 mm.). The middle band, directly adjoining the upper one, was narrow (about 1 mm.), ring-shaped, compact and dark-brown. The lower band, 6 to 8 mm. from the middle band, was broad (about 5 mm.), diffuse and light-brown. In ultraviolet light the upper band fluoresced weakly with a pale-yellow color; the remaining bands did not fluoresce. (The lilac-violet color of the lower part of the column in ultraviolet light is explained as the color of the starch itself.)

After standing, the column displayed the interesting phenomenon of depositing a new narrow ring upward from the middle zone. This kind of phenomenon is considered by Gapon (2) to be characteristic of sedimentary chromatography.

A somewhat different picture is shown by the chromatogram of the humic acid of peat-podzolic soil. With chromatography of 0.3 ml. of solution containing 0.45 mg. of material, as in the case of the humic acid of chernozem, only two broad bands were formed. They appeared brown in daylight. In ultraviolet light the upper band fluoresced a bright yellow-green but the lower band did not fluoresce.

If the concentration of the humic acid from peat-podzolic soil is increased to 0.80 mg. in the same volume (0.3 ml.), a middle band i formed at a distance of 3 to 4 mm. from the upper band in the shape of the same narrow compact dark-brown ring, just as in the chromatography of the humic acid of chernozem (see columns 2 and 5 of Figure 1).

With the fulvic acids, it was only when high concentrations (3 mg. per 0.3 ml. or 10 grams per liter) were used that we observed the formation of two directly adjoining light-brown bands, somewhat darker toward the bottom with the boundary between them clearly visible only in ultraviolet light; in ordinary light there was no clear boundary between them (column 1). The upper band of fulvic acids fluoresced bright yellow in ultraviolet light; the lower band did not fluoresce. In color, the fluorescence of the upper band of the fulvic acids was similar to the fluorescence of the upper band of the humic acids, especially of those from peat-podzolic soil, but the latter fluoresced more brightly and had a greenish tinge.

With elution of the chromatograms of humic substances on starch columns with distilled water, eventual downward movement of all the brown-colored bands was observed. At first the form of the bands did not change, but then they gradually ran together. On inspecting the locations of the upper bands in all the preparations (both of humic and fulvic acids) with ultraviolet light a fluorescing silvery-white or silvery-yellow belt was detected. The explanation for this phenomenon may be that some part of the humic substances (of humic and fulvic acids) enters into a sufficiently stable interaction with starch and, on the elution with water (and also with ethyl alcohol), remains in place in the upper part of the columns.

The chromatograms obtained show without doubt the heterogeneity of both humic and fulvic acids. Common to both is the presence of substances capable of entering a fairly stable reaction with starch and of fluorescing in ultraviolet light (formation of the upper bands). These substances are present to a greater degree in the fulvic acids and humic acid of peat-podzolic soil and to a smaller degree in the humic acid of chernozem. The formation of the middle and lower bands is possibly caused by the presence of humic and fulvic acid particles differing in size. The possibility of this kind of distribution of particles of organic substances in accordance with molecular weight in chro

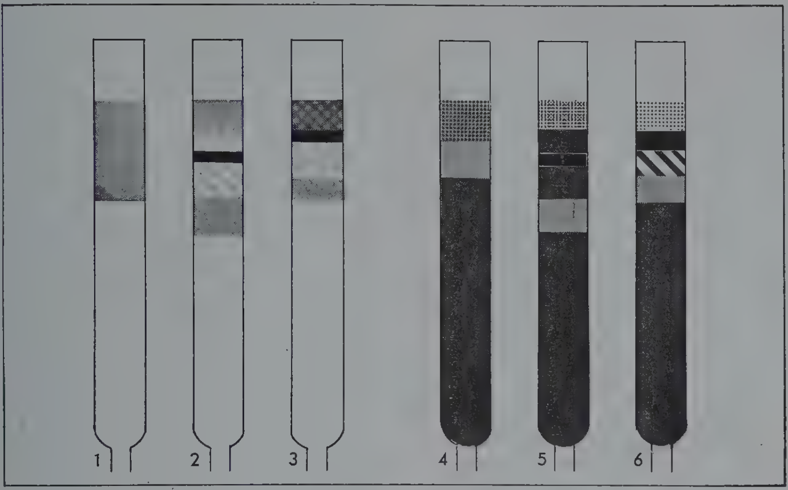

Fig. 1. Starch columns

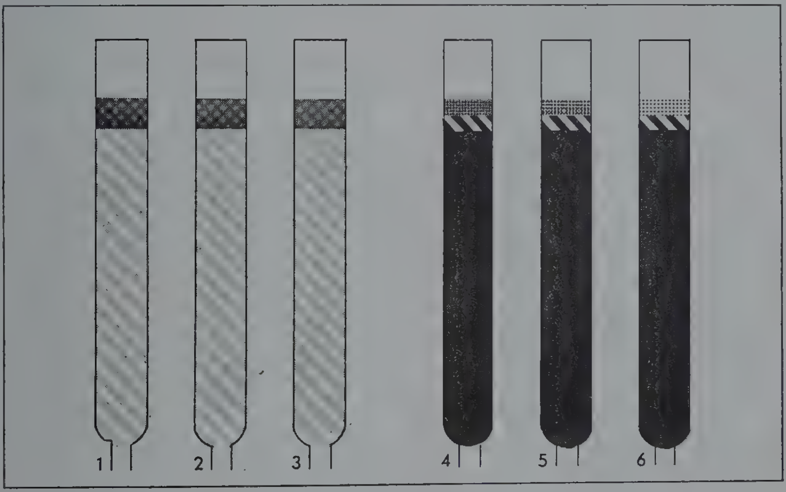

Fig. 2. Al_2O_3 columns

▩ Brown
■ Dark-brown
▒ Light-brown
▨ Ashy white
□ White
░ Pale yellow
▦ Bright yellow-green
▓ Bright yellow
▧ Pale violet
■ Lilac violet
▧ Brownish gray

matography on starch has been noted by Lathe and Ruthven (16).

In the composition of the humic acid of chernozem there is evidently a sufficient number of condensed, complex particles to form the middle band in the shape of a compact dark-brown ring. Particles of this kind are present in the humic acid of peat-podzolic soil but in smaller quantity, since the formation of the middle band is observed in the chromatography of this preparation only when the concentration of the material is increased to 0.80 mg. in the given volume of solution (0.3 ml.).

In the composition of fulvic acids, complex condensed particles are evidently absent (or their representation is minimum), since even with high concentrations (3 mg. in 0.3 ml. of solution) the formation of a middle band is not observed.

Common to both the subjects of investigation is also the presence in their makeup of less complex, and therefore more mobile particles which go down quickly on chromatographing and form the lower zone.

The idea which has been expressed—that the formation of the middle and lower bands is explained by the difference in size (and correspondingly, in complexity) of the particles forming these bands—is confirmed indirectly by data from the determination of the optical density of the humic substances of these zones. To determine the optical density the starch columns with chromatograms of humic substances were taken out of the tubes by extrusion with compressed air and sectioned along the visible borders of the bands. The humic substances of the middle and lower bands were easily eluted from the starch by a single treatment with distilled water; to obtain a sufficient quantity of the humic substances it was necessary to use a series of columns. Then followed filtration of the solutions through a dense paper filter, equalizing their carbon content and examination of them in a Pulfrich photometer (the method is described in the article by Bel'chikova [1] and also in the Kononova monograph [5]).

TABLE 1

Value of the coefficient of light reduction by solutions of the humic acid of chernozem (concentration of the carbon of the humic acids was 0.0475 grams per liter)

Humic acid of chernozem	Wave length in millimicrons						
	726	665	619	574	533	496	465
Middle band	0.18	0.27	0.34	0.45	0.58	0.69	0.82
Lower band	0.16	0.20	0.28	0.37	0.48	0.64	0.76

The results of determining the coefficient of light reduction characterizing the values of optical density of the substances tested in a layer 1 cm. thick are shown in Table 1. They show that the optical density of the humic substances of the middle band is higher than those of the lower band (the data shown are for the humic acid of chernozem).

In agreement with our earlier papers, we consider that the optical density value of the humic acids reflects in some measure the degree of condensation of the aromatic nucleus in their particles and therefore the degree of particle complexity. The data obtained are evidence that the middle band of the chromatograms is actually formed by more complex particles of humic substances than those of the lower band.

Results of Chromatographing: Activated Aluminum Oxide Columns

The chromatograms of humic substances on Al_2O_3 have a somewhat different character. Both humic and fulvic acids formed two bands on the Al_2O_3 columns. Under daylight both bands were brown; the upper band was narrower, the lower wide (see Figure 2, columns 1, 2 and 3).

In ultraviolet light the upper (narrow) zones fluoresced yellow and a yellow-greenish color, just as in the chromatograms on starch; the lower zones did not fluoresce (see Figure 2, columns 4, 5 and 6).

The interaction of humic substances and Al_2O_3 appeared to be irreversible and attempts to elute the bands with different reagents were without success. Thus, when the column was eluted with ethyl, methyl or butyl alcohol, benzene, solutions of 0.02 and 0.1 N alkalies or acids, a 5% solution of oxalic acid, a 0.1 N solution of cobalt nitrate or a series of other reagents, no movement of the zones was observed. Only when eluted with pyridine or a 10% solution of ammonia did the lower band begin to diffuse. Evidently the preparation of aluminum oxide by the method described above produced an exceptionally active adsorbent of humic substances which made it difficult to divide them into bands.

Conclusions

1. Chromatography on starch and aluminum oxide columns showed the heterogeneity of the humic and fulvic acids of peat-podzolic soil and of ordinary chernozem.

In their composition we detected three groups of particles differing in their interaction with starch and aluminum oxide and in their fluorescence under ultraviolet light.

2. The ratios of these groups differ in the subjects studied. In the fulvic acids there is a well-expressed group of particles capable of a fairly stable reaction with starch; the band in which these particles are located (in the upper part of the column) fluoresces brightly. This group of particles is represented fairly distinctly in the humic acids of peat-podzolic soil and most poorly in the humic acids of chernozem.

3. Two groups of particles have a less stable reaction with starch; they form bands because of a different rate of sedimentation, caused, possibly, by differences in the size (and corresponding complexity) of the particles.

The greatest quantity of complex particles forming a clear middle band on the starch column was found in the humic acids of chernozem; there were less of them in the humic acids of peat-podzolic soil; and they were either present in exceptionally small amounts or completely absent in fulvic acids.

In the formation of the lower band, which is composed of particles less complex than in the middle zone, no material differences were noted in the subjects of study.

The middle and lower bands did not fluoresce in ultraviolet light.

4. The reaction between humic acids and Al_2O_3 appears to be an irreversible one in which both humic and fulvic acids were observed to form two bands: the upper bands fluoresced in ultraviolet light but no fluorescence was observed in the lower bands.

5. Having established chromatographically the heterogeneity of humic and fulvic acids, we consider it necessary to note also that the data obtained revealed traits of similarity between these two representatives of the humic substances. This is manifested by the presence in both humic and fulvic acids of groups of particles which behave identically on starch and aluminum oxide columns and which have the same ability to fluoresce in ultraviolet light. The ratios of these groups of particles are different in the humic acids of different soils and in fulvic acids.

We believe that it is necessary to develop further the chromatographic method for the study of humic substances. It is particularly necessary to try out different adsorbents and to study in greater detail the nature of the substances forming the separate bands.

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VARIANCE ANALYSIS IN MICROBIOLOGICAL RESEARCH[1]

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IN 1951 research was carried out to determine the variation of microbiological properties of continuously-irrigated light colored sierozem in the area of the SoyuzNIKhI (Vsesoyuznyi nauchno-issledovatel'skii institut khlopkovodstva, The All-Union Scientific Research Institute for Cotton Growing) and the Vaksh valley of the Tadzhik SSR.

The research was done on a plot with an area of 224 m², where L. P. Belyakova had set up an experiment in plowing under clover plants at different depths (25, 35 and 45 cm.) under cotton sowings; regularly every ten days she made observations on the course of the soil's microflora development. The purpose was to determine the rate at which organic matter decomposed at different depths according to the quantity of microorganisms in the soil.

A uniform plot was chosen. Its gentle overall slope allowed irrigation via the furrows from a ditch. The irrigation ditch, in the form of a small canal with a settling pool, was located at the upper part of the plot at a right angle to its slope.

To determine variation in the distribution of microorganisms, soil samples were taken simultaneously on Oct. 22, 1952 from depths of 0 to 15 cm. along the length of the plot from above downwards at equal intervals (70 cm.). These samples were processed the same day to determine: 1) the total quantity of bacteria by the serial dilution method on Gil'tai's medium; 2) the number of nitrifying bacteria by the same method on Winogradsky's medium; 3) azotobacters of a soil sample sprinkled on Ashby's agar; 4) aerobic microorganisms which destroy cellulose, by the method of soil plates; and 5) the field moisture of the soil by a generally accepted method.

The results are evidence of the connection between factors of the external medium, soil moisture, and the distribution of microorganisms (see Figure 1). Thus, the gentle slope of the plot (from left to right in Fig. 1) and the constant action of irrigation in the upper part accounted for the fact that the soil moisture in this part was higher at the time the samples were taken. It was much lower toward the middle. At the end it rose again, probably as a result of a certain accumulation of water here during irrigation.

The soil moisture distribution, which depended on the slope of the plot and the location of the irrigation canal, clearly affected the distribution of the microorganisms reflecting to some extent the soil moisture curve. This relation is especially distinct for azotobacters and nitrifying bacteria. The quantity of decomposing-cellulose organisms is related less to a change in soil moisture and in many cases is subject to unrelated fluctuations. The total quantity of bacteria increases with an increase in soil moisture, but not significantly. It follows that fluctuations in moisture content of 12 to 19% produce little change in the vital processes of the great miscellaneous group of microorganisms.

In Waksman's opinion, differences in the quantity of microorganisms depend on uneven distribution of soil moisture in some cases, and in others, on the distribution of fertilizers. Waksman notes that the struggle for existence is reflected less on the quantity of microorganisms than on individual physiological groups (6).

To determine the degree of variation and accuracy of the data, the results of the observations were subjected to the formulas for variance analysis (3). For each type of microbiological analysis and for the soil moisture, calculations were made of the arithmetic mean (M) by the method of moments; the standard deviation (σ) by the method of moments with a correction for the small number of observations, by the formula:

$$\sigma = \sqrt{\left(\frac{\Sigma Pa^2}{n} - b^2\right)\cdot\frac{n}{n-1}},$$

in which P is the frequency, a the deviation from

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[1] In publishing this article by A. F. Zakharchenko, the editor directs attention to the desirability of using variance analysis in the quantitative calculation of soil microorganisms by other methods (that it, those of Winogradsky, Kholodnyi and others).—Ed.

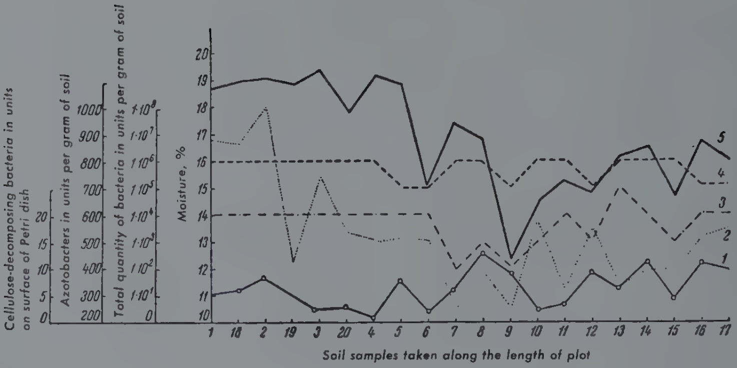

FIG. 1

the weighted mean, n the number of samples, and b the correction of the mean; also calculated were the standard error of the mean (m); the index of accuracy of the mean (P in %); and the coefficient of variation (v in %).

Further, according to the formula

$$n = \frac{t^2 \cdot v^2}{P^2},$$

which was suggested by investigators who worked at the Malouzensk Statistical Laboratory (1), we calculated, following the example of Kader (2), the number of samples (n) necessary for a definite degree of accuracy. According to this formula, the number of samples taken for analysis (n) should equal the square of the coefficient (t^2) corresponding to a probability o w% multiplied by the square of the coefficien of variation (v^2) and divided by the square o the accuracy of the mean (P^2). The latte amount (P^2) represents the square of the accuracy with which we will work. We chose th value of $t = 2$, having thereby established tha all further calculations will be carried out at probability of $w = 0.954$ (95.4%), which mean 19 correct observations out of 20 (1, 2, 3).

But this formula is used for the determination of the degree of accuracy in work with definite number of samples (n), in which $P =$ $t \cdot v / \sqrt{n}$. The results of the calculations ar shown in Table 1.

The calculations shown in Table 1 show tha

TABLE 1

Results of statistical treatment of data from microbiological and field moisture analyses of irrigated coarse-textured sierozem

Determination	No. of determinations, n	Arithmetic mean $M = v_0 + b$	Standard deviation $\sigma = \sqrt{\frac{\Sigma pa^2}{n} - b^2 \cdot \frac{n}{n-1}}$	Error of mean $m = \pm \frac{\sigma}{\sqrt{n}}$	Index of accuracy $P = \frac{100 \cdot m}{M}$ %	Variation coefficient $v = \frac{100 \cdot \sigma}{M}$ %	Determination of minimum number of samples to get mean with accuracy in % of:								Degree of accuracy with samples numbering		
							15	20	25	30	40	45	50	60	5	3	2
Total number of bacteria (× 10^{-3}/gm. of soil)	20	865	329.71	73.76	8.52	38.11	26	14	9	6	4	3	2	2	34	44	53
Azotobacters (in units per gram of soil)	20	524.5	206.56	46.19	8.8	39.38	28	15	10	7	4	3	2	2	35	45	60
Nitrifying bacteria (× 10^{-3}/gm. of soil)	19	7.06	4.46	1.02	14.4	63.03	71	40	25	18	10	8	6	4	56	73	89
Those decomposing-cellulose (in units on surface of cellulose)	19	6.1	3.6	0.82	13.44	59.0	62	35	22	15	9	7	6	4	53	68	83
Field moisture (%)	20	16.85	1.98	0.44	2.61	11.8	2	1	1	1	1	1	1	1	11	14	1

there is great variation in the distribution of microorganisms in the upper layer of the soil. There is especially large variation in the content of nitrifying bacteria (the coefficient of variation $v = 63\%$), so that repeating it three times would amount to an accuracy $P = 73\%$ (percent error). For the distribution of aerobic cellulose-decomposing organisms the coefficient of variation is 59%. Thus, for this group of microorganisms three samples afford an experimental accuracy (percent error) of 68%. To work with an accuracy of 40 to 45% it is necessary to make 8 to 10 observations on nitrifying bacteria and 7 to 9 on those decomposing cellulose.

The variation range of the total number of bacteria and of the azotobacters in this case is much less than with the nitrifying and cellulose-decomposing bacteria (the coefficient of variation $v = 38$ to 39%). Accordingly, the error of the mean is less (the index of accuracy $P = 8.5$ to 8.8%), which allows us to work with an accuracy of 44 to 45% when we repeat it three times, as we customarily do.

The variability of the total number of bacteria cannot be explained by errors in analysis methods, since a control analysis of one sample which we repeated eight times showed that the error of the investigation was zero (Table 2).

TABLE 2

Total number of bacteria in a sample of continuously-irrigated light-colored sierozem from a depth of 3 to 10 cm. at the Experimental Station of the Soyuz-NIKhI

Replications	1	2	3	4	5	6	7	8
No. of bacteria ($\times 10^{-3}$/gm. of soil)	1000	1000	1000	1000	1000	1000	1000	1000

The table, showing the lack of variation in the analysis of a single sample, obliges us to attribute the variation of this criterion to the varation of the plot. The control analysis results may be explained by the high uniformity of the sample and by the fact that the analytical method allowed us to consider only values which are multiples of 10 without any intermediate figures.

With the serial dilution method, only those soils having a high dispersion give results approaching the expected number of bacteria, while carbonate soils with a high content of organic matter show sharp variations in the number of bacteria counted from the same sample (4). For this reason it is necessary to carry out control analyses separately for each soil.

From the research of Lavern' Ozh'ye it appears that the proportion of bacteria in carbonate soils is considerably higher than expected; the author explains this by the decalcination of organomineral complexes in the serial dilution process, with the release of bacterial cells (4).

Our determination of the uneven moisture distribution (see Table 1) showed that the field moisture unevenness was less widespread than that of the microorganisms. The coefficient of variation (v) is 11.8%, which makes it possible for us to work with an accuracy (P) of 15% with two samples. This is also confirmed by the data of other investigators (1, 2, 5).

Table 1, shows the variation in the distribution of some groups of microorganisms and the variations of field moisture. We may therefore estimate the accuracy of the observations on the development rate of this plot. From these it follows that repeating the observations three times gave the following accuracy (P = percentage error): in the determination of the total number of bacteria, 44%; that of azotobacters, 45%; that of nitrifying bacteria, 73%; that of aerobic decomposing cellulose microorganisms, 68%; and for the soil moisture determination, 14%.

To prove the reliability of the data obtained from the experiment in the study of the decomposition rate of soil organic matter at various depths, after calculating the mean (M), the standard deviation (σ), the error of the mean ($Vb \pm m$), the index of accuracy (P in %) and the coefficient of variation (v in %), we also calculated the significant difference between means (T) for the basic treatment of the experiment according to the formula:

$$T = \frac{M_1 - M_2}{\sqrt{m_1^2 + m_2^2}} \quad \text{or} \quad T = \frac{(M_1 - M_2)^2}{m_1^2 + m_2^2};$$

here we took as a basis the fact that if the ratio of the difference between means of two independently measured values ($M_1 - M_2$) to the square root of the sum of the mean errors, $\sqrt{m_1^2 + m_2^2}$, is more than 3, then the difference between the means is significant.

By this formula we verified whether the difference of the mean data on the quantity of microorganisms and soil moisture for the entire period of the observations exceeded three times the mean error, since the mean error is an index of the reliability of the experiment. The result was that 99.7% of all the treatments were within the limits of $M \pm 3m$ and only 0.3% were outside this limit (3).

Calculations for significance of the difference between means was carried out only for the basic treatments of the experiment described previously on the plowing under of clover at different depths.

The mean quantity of microorganisms and field moisture at a depth of 15 to 25 cm. plowing under the clover to 25 cm. was compared (14 observations every 10 days) with the mean quantity of microorganisms and moisture at a depth of 35 to 45 cm., plowing under the clover to 45 cm., and, in one case, at a depth of 25 to 35 cm. plowing under the clover to 35 cm. Each of the 14 treatments (corresponding to the number of dates of the observations) represented the arithmetic mean of three observations. The results in Table 3 show significant difference between means of the total quantity of bacteria and of azotobacters in the treatments described, because each exceeds its error by more than 3 times. For the soil moisture the difference between means may also be considered as significant ($T = 2.9$), but for the nitrifying bacteria ($T = 1.93$) and even more for the aerobic decomposing cellulose microorganisms ($T = 0.34$), the difference between means is not significant. For nitrifying bacteria this may be explained by the considerable variation of their distribution in space, so that three samples in this case are not enough. According to the theory of probability three samples can provide an accuracy in the experiment (percent of error) of 73% (see Table 1). Unfortunately the control analysis to show the error of the investigation was not carried out by us. It can be assumed, however, that the nitrifying bacteria, being strictly specialized and having only two species in all, should reflect the state of the soil very sensitively. This is in agreement with Shulgina's opinion (6).

The significance of the difference between means for the aerobic decomposing cellulose microorganisms is not surprising. On the basis of our data, the unsatisfactory method of investigation explains the high proportion of variation of this criterion. Considering the spots in colonies and counting them on cellulose by the method of soil plates on the fifth or tenth days, does not achieve the purpose since, by this time, there are often no spots or they are piled on top of one another, or they fuse together so that th boundaries between them cannot be distin guished. Under such conditions the fused spo must be omitted in the count or most of th observations must be completely rejected.

Considering the great variability of the micro biological properties of the soil in time an space, the use of variance analysis in dealin with the data from microbiological research even more indispensable than in the study physical and chemical properties. If an exper ment is set up incorrectly, a statistical trea ment may lead the investigator to form fals scientific conclusions.

We consider it necessary for the productio of reliable data to carry out microbiological ex periments as follows:

1. A primary necessity is a careful study o the variation in the distribution of the micro biological and basic physicochemical properti of the soil, which are interdependent. Take fro 10 to 100 samples in strict order in rows alon and across the plot. This makes it possible b graphic representation and other means to de tect the relation between the various soil prop erties and the place where the sample was take

2. Analysis of all the samples to determi variation, as well as a composite sample fro them all to determine the error of the analys should be carried out simultaneously.

3. The number of observations should be ade quate (up to 100) to reveal to what extent th distribution variation of the microbiologic properties obeys the law of the normal distribu tion of probabilities, and to what extent it woul be possible to use with confidence the formula for variance analysis. To collect the necessar number of observations, one can construct single distribution figure ("polygon") (1, 3) fo all the horizons investigated.

4. The results of the determination of varia tion and control analysis are treated mathe matically by using the formulas for the varianc analysis.

5. The data from the determination of varia tion in distribution of the soil properties, de pending on their complexity, are compared wit data from the determination of the error of th investigation; here the determination is mad of the extent to which the error of the invest gation is manifested on the index of plot var ation.

TABLE 3

Significance of the difference of the means between treatments of the experiment in plowing under clover at different depths

Determination	Depth plowed under, cm.	Depth of sample, cm.	No of determinations, n	Arithmetic mean, M	Standard deviation σ	Error of mean, $m = \pm\frac{\sigma}{\sqrt{n}}$	Index of accuracy $P = \frac{100 \cdot m}{M}$ %	Variation coefficient $v = \frac{100 \cdot \sigma}{M}$ %	Signficant difference of means, $T = \frac{M_1 - M_2}{\sqrt{m_1^2 + m_2^2}}$	
Total number of bacteria (× 10^{-3}/gm. of soil)	25	15–25	14	734.3	239.381	63.98	8.7	32.6	3.21	Difference between means is significant, since it exceeds its error by more than 3×
	35	25–35	14	447.14	235.05	62.8	14.04	52.56		
Total number of bacteria (× 10^{-3}/gm. of soil)	25	15–25	14	734.3	239.381	63.98	8.7	32.6	3.29	same
	45	35–45	14	385.0	316.56	84.88	22	82.2		
Azotobacters (units/gm. of soil)	25	15–25	14	622.65	225.18	60.2	9.68	36.2	3.74	same
	45	35–45	14	340.22	169.86	45.41	13.35	49.9		
Soil moisture, %	25	15–25	14	16.9	5.22	1.39	8.2	30.2	2.92	same
	45	35–45	14	22.7	5.18	1.43	6.3	22.8		
Nitrification bacteria (× 10^{-3}/gm. of soil)	25	15–25	42	41	44.6	6.88	16.78	108.7	1.93	Difference between means not significant
	45	35–45	41	24	35.05	5.47	22.7	146.08		
Aerobic decomposing cellulose micro-organism (in units on surface of Petri dish)	25	15–25	14	77.6	82.23	21.9	28.22	105.96	0.34	same
	45	35–45	14	67.4	76.23	20.37	30.22	113.1		

6. Using the coefficient of variation by the formula:

$$n = \frac{t^2 \cdot v^2}{p^2}$$

determination is made of the lower limit of the number of samples at which the error of the mean does not exceed desirable limits. In this the value of t may be assumed to be 2, thereby establishing that all further calculations are carried out with a probability of 95.4%, or 19 correct calculations of 20. The value of t can be changed if we remember that the closer the probability approaches 100%, the greater the number of samples required at the same degree of accuracy of the experiment.

The number of samples established as required for a definite degree of probability is the approximate minimum number necessary for all protracted observations on the plot with a definite degree of accuracy.

7. Further, the accuracy of the data from the observations of development (by the use of the established number of samples) may also be verified by the use of the formulas for the variance analysis with a simultaneous check of the reliability of the experiment (by significance of the difference between means).

8. This method of setting up an experiment—with the need for systematically carrying out control investigations—makes it possible to establish the accuracy of this or other methods for various soils. Then the accuracy of this or other methods will show the degree of acceptability.

Conclusions

1. A study of the variation of a plot according to microbiological criteria should always precede a prolonged study, since these data on soil variation establish the minimum number of samples which will assure the desired degree of accuracy of the long-term observations. Such a study is also necessary for making single observations, since it assures the production of reliable data for characterizing any soil.

2. Control analyses make it possible to correct for the soil variation in the data obtained and give an idea of the degree of error in general and for different soils in particular.

3. The investigation carried out to determine the variation of a sierozem on a continuously-irrigated plot showed a considerably greater variation in space of the microorganisms than of the soil field moisture.

4. The variability of the total quantity of bacteria and of azotobacters on continuously-irrigated sierozem (coefficient of variation v = 38 to 39%) makes it possible to work with three samples with an accuracy of 44 to 45%. Here the difference between means of the data is significant.

5. The variability of the quantity of nitrifying bacteria (including the error of the method) makes it impossible to work with only three samples. This shows that the accuracy of the experiment (percentage of error) is 73%. Only the collection of 8 to 10 samples gives an accuracy of 40 to 45%.

6. Aerobic decomposing-cellulose organisms are also subject to great variation in space (including the error of the method). Therefore it is necessary to work with 7 to 10 samples to get an accuracy of 40 to 45%. Three samples afforded an accuracy of only 68%. The problem of the accuracy of the method of soil plates remains unsolved. It may be assumed that the error of this method is high.

7. The field moisture varies very little in space compared to the number of microorganisms. This makes it possible to work with two samples at an accuracy of 15%.

8. Significance by the difference between means of the observations of development on the continuously-irrigated plot of light-colored sierozem confirms the calculation of the number of samples necessary depending on the variation. The difference between means for the total quantity of bacteria, azobacters and field moisture as calculated from three samples was significant, while for the nitrifying bacteria and aerobic decomposing cellulose microorganisms it was not significant.

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EFFECT OF AGRICULTURAL PRACTICES ON WATER INTAKE OF SOIL

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WATER permeability of the soil is a very important indicator of its hydrophysical properties. The water relations of the earth's surface are associated with the phenomenon of water intake into soil.

Water intake into soil was the subject of work by I. N. Antipov-Karatayev, N. A. Kachinskii, S. I. Dolgov, A. N. Kostyakov, N. F. Sozykin, M. F. Sribnyi and many others. The investigations were carried out in soil monoliths and also in soil of undisturbed structure under natural field conditions.

It was established that the amount and rate of water infiltration are affected not only by the soil texture but also by a number of factors which are difficult to calculate, such as initial soil moisture, plant cover, bulk density of soil, its porosity, the presence in the soil of organic residues, cracks, worm holes and the roots of grassy plants, the soil structure, and so forth. The effect of tillage on the water intake into soil has not yet been sufficiently elucidated in the literature. For the last few years (1949 to 1956), to clarify this, we have been making a study of water intake into soil in both winter and summer. With the Nesterov apparatus containing a constant depth of 5 cm. of water, determinations were made of the total water intake in millimeters and the rate of water intake with different agricultural practices (millimeters per minute).

The experiments were carried out on the Kamennaya Steppe irrigated crop rotation fields of the Dokuchayev Institute of Agriculture. The crop rotation was located on the slope of a northeastern exposure. The soil of the tract was uniform and consisted of ordinary chernozem 0.6 to 0.8 m. thick underlain by deposits of clay loam.

Table 1 gives the characteristics of farm lands on which the experiments took place and the indices of the rate of water intake in a 150 minute period (carried out by Ye. M. Sukhareva). Figure 1 shows graphically the curves of the total water intake into soil. As seen from the table and the graph, the greatest amount of water intake was by unmowed steppe.

The least water intake was observed on pasture and fallow (on a continuously-tilled plowed tract) where the soil was strongly dispersed or compact.

The water intake rate curves (Fig. 2) show the same pattern as the curves of the total intake. In places where there is a high total water intake, there is also a high absorption rate. The curves (Figs. 1 and 2) provide very clear reflections of two stages: the stage of entry and the stage of established filtration. For some experiments (5, 7, 8 and 9) the entry stage was 10 to 15 minutes; for experiments 2, 3, 4 and 6 it was 20 to 25 minutes and for experiment 1 (unmowed steppe) it was 40 to 45 minutes from the beginning of the experiment. Usually, the more pronounced the soil structure, the longer the stage of entry. On soils with an undisturbed structure (Fig. 2), the highest rate of water entry is seen at the beginning of the stage. This is caused by the saturation of the dry upper layer of the soil filling the large pores, holes and cracks. The effect of these large pores, holes and cracks on water intake is great, but does not last long because they become filled from the top soil layer when there is a constant depth of surface water.

All the information presented before suggests that the surface condition, the kind of tillage, and the agricultural practices play large roles in the process of water intake into soil.

If the amount of water intake (500 mm.) by the soil in 150 minutes in the experiment on mowed steppe is taken as unity, the amount adsorbed on non-mowed steppe is 2.94. On the surface of a field of spring wheat it is 1.88 and on the inverted furrow slice 1.48. In a forest strip it is 1.1, on a field of lucerne 1.07, on a continuously-tilled field of spring wheat 0.88, on fallow 0.57, and on continuously-tilled fallow 0.53.

To calculate the elements important in irrigation practices and soil reclamation, the formula of Academician Kostyakova is widely used

TABLE 1

Water intake into soil of different types of farm land

Experiment No.	Type of farm land	Volume weight of soil layer 0–30 cm.	Water stability of aggregates in %, 0–10-cm. layer		Soil moisture 0–30 cm. layer, %	Total intake of water in mm. in 150 min.	Steady rate of water intake at end of experiment, mm./min.
			>1 mm.	>0.25 mm.			
1	Steppe not mowed since 1882	0.71	47.3	84.7	21.0	1470.0	6.3
2	Field of spring wheat on 3-year sod.	0.96	31.0	76.0	28.6	939.1	4.0
3	Inverted topsoil	0.98	24.0	74.0	27.3	742.0	3.5
4	Forest strip, 60 years old	0.89	45.2	84.4	30.0	546.6	2.1
5	Field of alfalfa (continuously-tilled)	1.09	8.7	73.0	26.7	535.0	1.1
6	Mowed steppe	1.02	36.1	84.8	19.0	500.0	2.2
7	Continuously-tilled field of spring wheat	0.98	11.4	79.2	21.2	440.0	2.1
8	Fallow (pasture)	0.98	14.3	70.8	19.0	283.0	1.3
9	Continuously-tilled field in fallow	1.04	7.1	68.0	25.6	262.0	0.8

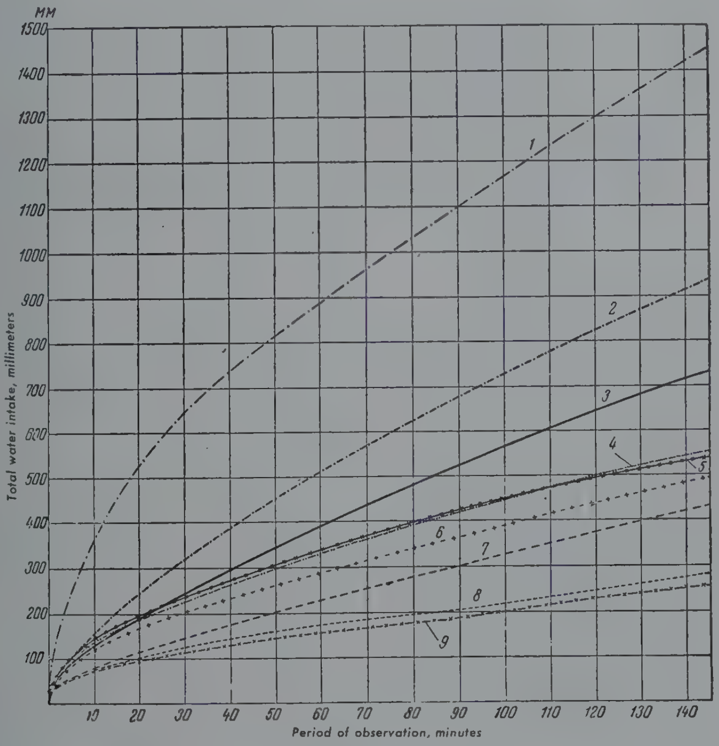

FIG. 1.—Curves of total water intake into the soil. 1—Not mowed steppe; 2—field of spring wheat on three-year sod; 3—inverted topsoil; 4—forest strip; 5—alfalfa field, 1st year of use; 6—mowed steppe; 7—continuously-tilled field of spring wheat; 8—continuously fallow (rotation pasture); 9—continuously-tilled plot.

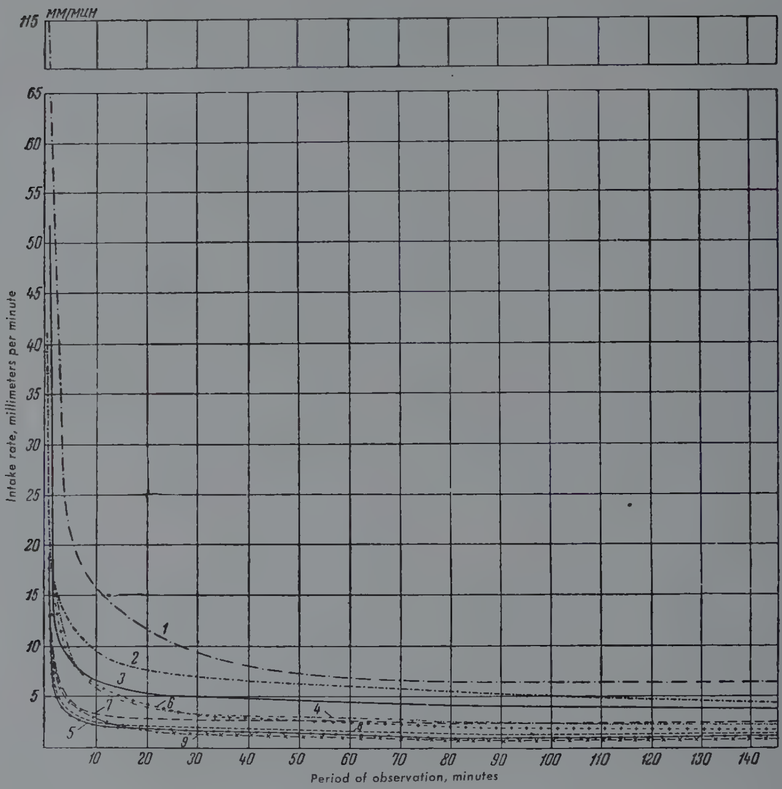

FIG. 2.—Rate of adsorption of water by the soil on different kinds of farm land. (For numbering of curves, see Fig. 1.)

for determination of the intake rate in a period of time t:

$$v_t = \frac{v_0}{t^a}$$

in which v_t is the rate of intake (millimeters per minute) for any moment of time from the beginning of adsorption, v_0 is the rate of water intake into the soil for the first unit of time (millimeters per minute), and α is an index of degree for a given soil which must be determined experimentally.

On the basis of these experiments (Fig. 2) and using the method of least squares, we determined the values of v_0 and α for all nine experimental tracts (Table 2).

As seen from Table 2, the value of the rate v_0 for fields varies from 7.12 to 20.8 millimeters per minute, that of α from 0.281 to 0.488. Nonmowed steppe has a very high value for v_0—76 millimeters per minute—while v_0 for forest strips is 28.8 millimeters per minute.

The filtration capability of soils has been studied on different farm lands with a special sprinkling set-up in which the amount of water intake was determined as the difference between the amount sprinkled and the runoff. (The experiments were carried out by Ye. N. Tsykin, I. P. Sukharev, M. I. Agapova, V. I. Afonin and G. P. Alekseyev.)

The area sprinkled was 1.5 m². The sprinkling rate was 4.5 millimeters per minute. To avoid the loss of water into the soil surrounding the plot, a special metal sheet was placed around its perimeter and driven 10 cm. into the ground. The basic indices of the conditions and results of the experiments are shown in Table 3 and Figure 3.

On thoroughly loosened soils with a proounced structure the amount of water intake in this set-up was higher than the amount of intake on dense soils with a dispersed surface layer. Maximum intake was observed on the nversed furrow-slice of fall-plowed land. On fall-plowed fallow with a dispersed surface horizon the intake rate was considerably lower. In experiments 6 to 9 the highest intake rate was on virgin soil on which the grass had been cut, but which was not yet converted to pasturage (experiment 6), while the lowest rates were on grasses and rotational pasture (experiments 9 and 8, respectively). The intake rate in a forest strip 45 years old (experiment 10, Fig. 3) was considerably higher under varying conditions of intake than the rates of those 5 and 15 years old (experiments 11 and 12, Fig. 3). The soil of 5-year-old forest strip had almost the same infiltration properties as the soil of fields. Figure 3 (experiment 14) shows the curve of the intake rate by the soil of forest strip No. 74 (45 years old). Runoff did not begin in this experiment until the 117th minute from the beginning, before which all the water entered the soil. At the end of the experiment, which lasted 370 minutes, the rate of intake was 3.3 millimeters per minute. In this experiment the water was applied to the area in large quantities.

Of special interest is the intake of water by nonmowed virgin steppe (experiment 13, Fig. 3). This plot, as mentioned before, had not been mowed since 1882. The soil had a good structure. For the 330 minutes of the experiment all the water sprinkled on at 4 to 5 millimeters per minute entered the soil without runoff. Runoff did not begin until 1470 mm. of water had been sprinkled on. The intake rate during the entire experiment was very high and at the end had settled down to a constant rate of 3.7 millimeters per minute.

TABLE 2

Experiment No.	Type of farm land	v_0 in mm./min.	α
1	Steppe not mowed	76.0	0.599
2	Field of spring wheat on 3-year sod	20.8	0.298
3	Inverted topsoil	14.8	0.314
4	Forest strip, 60 years old	28.8	0.592
5	Field of alfalfa (1st year; on continuously-tilled field)	8.4	0.454
6	Mowed steppe	25.4	0.630
7	Field of spring wheat on continuously-tilled field	7.12	0.281
8	Fallow (pasture)	4.0	0.161
9	Continuously-tilled field in fallow	8.5	0.488

TABLE 3

Rate of water intake into soil with sprinkling

Experiment No.	Type of farm land	Mean soil moisture in layer 0–40 cm., %	Depth of sprinkled water, mm. before beginning of runoff	Rate of water intake (mm./min.) when constant conditions established
1	Fall-plowed for spring sowing with furrow slice inversion	14.0	85	1.55
2	Stubble of spring wheat at end of crop rotation	12.0	50	1.55
3	Virgin steppe	10.2	15	1.7
4	Stubble of spring wheat on surface	12.5	40	1.90
5	Fall-plowed fallow	17.0	70	1.2
6	Virgin steppe, mowed but not converted to pasture	17.5	112	2.0
7	Fall-plowed for sowing spring crop, end of rotation	26.5	100	2.0
8	Rotation pasture	18.8	15	1.70
9	Grasses, first year of use	17.0	45	0.65
10	Forest strip No. 74 (45 years old)	20.5	150	1.70
11	Forest strip No. 123 (15 years old)	12.7	70	1.70
12	Forest strip No. 131 (5 years old)	13.3	55	1.5
13	Steppe not mowed	22.5	1470	3.70
14	Forest strip No. 74 (45 years old)	19.5	520	3.3

Intake of Snowmelt by Frozen Soil

The entry of snowmelt by frozen soil during thaws has not yet been sufficiently studied or clarified. Before the end of the last century (according to data in the literature) it was customary to consider that frozen soil was impermeable to water. At the beginning of the twentieth century a very interesting paper by Shalabanov (15) was published in which he showed for the first time that frozen soil conducts water, but he did not give a correct explanation of this phenomenon. We found the correct explanation of

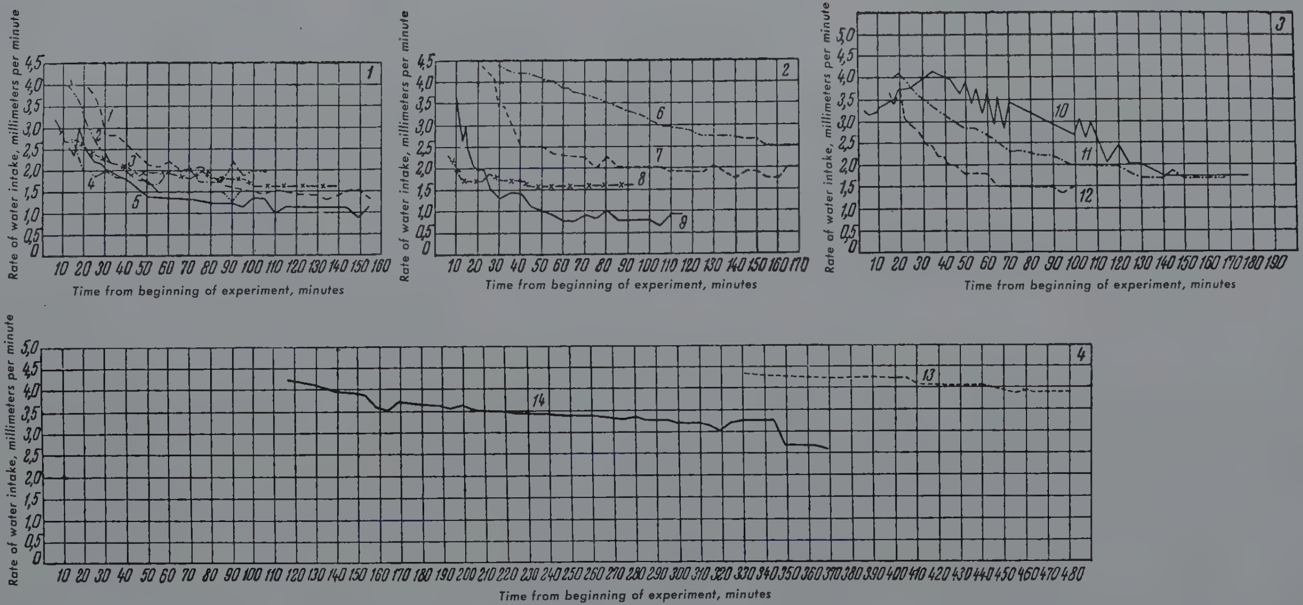

FIG. 3.—Water intake by soils of different farm lands with sprinkling. 1—Fall-plowed for sowing spring crop with furrow slice inversion; 2—stubble of spring wheat at end of crop rotation; 3—virgin steppe; 4—stubble of spring wheat with furrow slice inversion; 5—fall-plowed fallow; 6—virgin steppe, mowed but not converted to pasture; 7—fall-plowed for sowing spring crop, end of rotation; 8—rotation pasture; 9—grasses, first year of use; 10—forest strip No. 74 (45 years old); 11—forest strip No. 123 (15 years old); 12—forest strip No. 131 (5 years old); 13—non-mowed virgin steppe; 14—forest strip No. 74 (45 years old).

the process of infiltration of water into frozen soil in papers by Kachinskii (5) and Mosolov (8). Subsequently, in different zones of the country, studies of the process of this intake of water were made by the investigators Dmitriyev (4), Uryvayev (13) and many others. These investigators came to different conclusions because the water intake in different zones is not uniform; it depends on the natural and soil-climatic conditions of the area. Further, the observations were made in different years. Also, the water intake by the same frozen soil changes radically from one year to the next.

We made a study of the intake of snowmelt by frozen soil in the course of investigating runoff on permanent runoff plots (1948 to 1956) and in experiments on the direct measurement of the amounts of water adsorbed on different farm lands during thawing (1950 to 1956). On the permanent runoff plots for a number of years we studied the runoff of snowmelt and the role in water regulation of forest strips. The permanent installation consisted of 10 elementary runoff plots located on the eastern slope of the hollow of the Talovaya river. At the foot of the slope is forest strip No. 72, planted in 1907. Plots Nos. 1 and 10 of the permanent installation were located on a field of the slope 480 m. long and 20 m. wide. The remaining plots had the same area (480 by 20) and in addition the paired plots 2 and 9, 3 and 8, 4 and 7 and 5 and 6 were cut 10, 20, 30 and 45 m. into the forest strip respectively. During all the years when observations were being made the plots were plowed in the fall for spring crops. However, in 1953 they were covered with oat stubble with a secondary crop of perennial grasses and in 1954 with grasses.

These field plots made it possible to establish the amount and nature of the runoff and the amount of intake of snowmelt during thawing. On the plots cut into the forest strip, studies were made both of the role of forest strips of various widths (10, 20, 30 and 45 m.) in absorbing the runoff and also of the intake rate of snowmelt by the forest strip soil. We have previously given a detailed description of the permanent runoff plots (12).

The average data on the amount of intake of snowmelt by soil (1948 to 1956) on field and forest plots are given in Table 4. For all the years indicated, snowmelt intake occurred at a

TABLE 4

Intake of snowmelt by frozen soil

Indices	Year of observations									Nine-year average
	1948	1949	1950	1951	1952	1953	1954	1955	1956	
Deficit of soil moisture in mm. before thawing of 0–40-cm. layer[a]										
on field plots	67.0	55.0	107	49.0	57.0	42.0	99.0	9.0	60	—
on forest plots	—	—	108.4	67.0	97.0	34.0	79.0	63.0	86	—
Depth to which soil frozen before thaw (cm.)										
on field plots	50.0	45.0	45.0	60.0	50.0	50.0	40.0	35.0	50.0	—
on forest plots	25.0	20.0	30.0	18.0	25.0	12.0	28.0	18.0	20.0	—
Mean daily rate of thawing of snow in mm./24 hours										
on field plots	11.0	6.5	4.9	6.5	3.4	6.4	2.0	3.0	6.3	5.5
on forest plots	9.6	10.2	4.7	9.6	10.0	15.0	4.8	5.1	15.6	9.2
Duration of runoff in days	7.0	15.0	12.0	10.0	17.0	15.0	16.0	10.0	14.0	12.9
Mean daily intake of snowmelt by soil in mm./24 hours										
on field plots	6.1	4.4	4.1	5.8	2.5	1.2	1.8	0.9	3.4	3.4
on forest plots	71.5	53.5	23.6	29.5	22.5	42.1	12.0	9.8	47.0	34.6
Total intake of snowmelt during thaw, mm.										
on field plots	49.3	66.4	49.0	58.5	42.0	18.0	29.0	9.1	47.8	41.0
on forest plots	500.0	803.0	284.0	245.0	376.0	843.0	192.0	98.4	941	477.0

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[a] The moisture deficit in mm. was determined in our calculations by the difference between the full moisture capacity of the 0 to 40 cm. soil layer and the moisture present in this soil layer before thawing. The full moisture capacity is assumed to equal 85% of the soil porosity (15% of the pores occupied by trapped air).

higher rate during the period when the soil is usually still frozen to a considerable depth. The amount entered undergoes large fluctuations from one year to the next.

It must be noted that during winter thaws the upper horizon of the frozen soil is very often saturated with water almost to its full moisture capacity. In late fall the rain or snowmelt saturates the free pores of frozen water. This water, being unable to penetrate deeply, freezes in the pores of the upper horizons, decreasing the volume of the free pores and the deficit of soil moisture of these horizons. This causes a decrease in the permeability of the soil to water. In 1952, 1953 and 1955 we observed an ice crust form during the winter thaws, so that in these years the amount of intake of snowmelt during thaws was considerably less than in years when there were no such crusts on the soil surface.

The total intake of snowmelt during thaws on the field plots for nine years varied from 9.1 mm. in 1955 to 66.4 in 1949, and averaged 41.0 mm. On the forest plots for these nine years the intake was 98.4, 941.0 and 477.0, respectively. The smallest mean daily intake was observed on the field plots in 1955 and amounted to 0.9 millimeters per 24 hours. The greatest was in 1948—6.1 millimeters per 24 hours. The nine-year average was 3.4 millimeters per 24 hours. On the forest plots the mean daily intake was 9.8 (minimum) and 71.5 (maximum); the nine-year average was 34.6 millimeters per 24 hours.

The observation shows that the water intake by the frozen soil is highly variable in different years. Considerable intake is observed in years when the soil has a low moisture content before thawing. On the other hand, with a high moisture content in the upper horizons before thawing, intake of snowmelt occurs more slowly. With quick thawing the relative intake is less than with slow thawing. There is a considerable decrease in intake of snowmelt with the presence of a surface crust of ice formed during winter thaws.

Entry of snowmelt by frozen soil on different kinds of farm lands was studied in the springs of 1950, 1951, 1952, 1954, 1955 and 1956. On a level field of different kinds of farm land an area of the soil surface 40 by 40 cm. and 5 cm. deep was cleared of snow at the beginning of thawing. Snowmelt was obtained from under the snow at a temperature close to 0° C. With a graduate 600 to 1000 ml. of water was poured into the depression, filling it to a depth of 0.4 to 0.6 cm. Th water poured into the bottom of the depressic was absorbed. Then a second portion of the san volume of water was poured in. The experimer was carried out for an hour with two or thre repetitions. At the end of the experiment tl soil at the bottom of the depression had some times melted on top for not more than one t two cm., but in most cases it remained frozen.

Table 5 shows data characterizing the amoun of water intake by the soil on different types o farm land in different years. The entry of wate in different types of farm land takes place di ferently and is determined by the soil's moistur conditions and its structure and compactness. I the spring of 1950 there was a low soil moistur content in the upper horizons, so that there wa considerable water intake by the frozen soil. I January of 1952 there was a thaw, followin which a crust of ice was formed over the entir tract. The moisture in the upper horizons in creased considerably during the thaw. The mea soil moisture content by weight of the uppe horizon (0 to 30 cm.) before the thaw was 28.2% After the thaw it reached 45%, exceeding th maximum field moisture capacity of this layer Consequently, a part of the gravitational wate of the 0 to 30 cm. layer was frozen in the pores Increasing the moisture content of the uppe layer above the field moisture capacity (fillin the free pores with water which then turns t ice) considerably hinders the entry of snowmel during thaws. The soil which is frozen even witl such a moisture content is still permeable, al though only slightly.

In the spring of 1954, the soil had a low water content, so that the water intake by fall-plowed soil took place at a very high rate. In the winter of 1954–1955 there were four thaws with flooding. As a result of this, the upper horizons were supersaturated with moisture and crusts of ice were formed everywhere on the surface. Therefore, in the spring of 1955 the snowmelt was absorbed very slowly by the fall-plowed soil (the overall rate was 1.2 millimeters per hour). On the tract of virgin steppe at this time the intake rate was zero. On the forest strip water intake also took place very slowly.

Figure 4 shows graphically the nature of the water intake by frozen soil on different farm lands during these years. The highest intake rate took place in the spring of 1950 and 1954. The water intake into soil was completely differ-

TABLE 5

Amounts of water intake by the frozen soil of different farm lands

Experiment no.	Date of experiment	Kind of farm land	Depth to which soil frozen, cm.	Weight of soil moisture in %, 0 to 40 cm. layer	Moisture deficit in 0 to 40 cm. layer in mm.	Total water intake in mm./hr.	Mean intake rate in mm./min.
1	3/24/50	Fall-plowed soil	45	31.0	107	53.0	0.88
2	same	Winter wheat	65	27.0	96	32.0	0.53
3	same	Mowed steppe	70	27.5	95	31.8	0.53
4	same	Non-mowed steppe	40	31.5	78	168	2.7
5	3/25/50	Forest strip	35	32.5	108	72.0	1.2
6	4/3/52	Fall-plowed soil	42	42.7	18	4.8	0.08
7	same	Mowed steppe	45	34.0	51	3.1	0.052
8	4/4/52	Forest strip	15	27.0	83	94.0	1.57
9	3/20/54	Fall-plowed soil	45	31.0	64	32.2	0.53
10	same	Winter wheat	50	43.6	35	17.0	0.28
11	same	Perennial grasses	50	32.0	50	12.5	0.21
12	3/23/54	Mowed steppe	55	27.1	57	8.0	0.13
13	same	Non-mowed steppe	42	—	—	149.0	2.5
14	3/20/54	Forest strip	25	27.5	59	52.0	0.87
15	same	Spring wheat stubble	47	25.0	80	16.7	0.28
16	3/18/55	Fall-plowed soil	35	29.5	9	1.20	0.021
17	same	Mowed steppe	45	—	—	0.0	0.00
18	3/27/56	Fall-plowed soil	50	36.8	60	92.0	1.53
19	same	Winter wheat	68	29.0	89	64.0	1.07
20	same	Mowed steppe	45	35.5	62	60.0	1.00
21	same	Non-mowed steppe	27	49.0	9	317	5.28
22	same	Forest strip	30	28.0	86	123	2.05

nt in 1952 and 1955, when the soil had reeived abundant moisture during the previous all. In the spring of 1956 the soil had a low noisture content and for this reason showed ioticeable water entry on all the plots of farm and. The entry of snowmelt in all years is greatst in fall-plowed soil. Fall plowing is the best urface for retaining moisture on fields in the pring, as compared to others: winter crops, teppe, grasses, stubble, and so on.

It must be noted that in forest-strip, stubble, teppe and grasses water intake into frozen soil akes place fairly evenly in different parts of the ame field (or plot). The amounts of water aborbed in all experiments on these farm lands re usually in close agreement because of the niform compactness of the soil, its moisture, evelled surface, and so forth. In fall-plowed soil he water intake changes radically within the oundary of the same field because of different onditions in the physical structure of the plow ayer of the fall-plowed soil (the presence of lods, ridges, furrow bottoms, and so forth).

In the 1956 experiment, when the water intake y frozen fall-plowed soil was carried out eight imes, considerable variations in the amounts bsorbed were observed. The greatest amount f water intake per hour was 200 mm., the smallest 18 mm. The average of the eight replicates was 92 mm.

It should be noted that in spring, continuously-tilled soils, as a result of greater dispersion of soil in the upper horizons, are less permeable to water than plowed virgin land or peats. Plowed virgin land and peats absorb considerably more snowmelt during thaws in spring than do continuously-tilled soils. In the 1956 experiments on old, fall-plowed fields the snowmelt intake per hour was 32 mm., while on plowed peat it was 141 mm. Consequently, in spring, plowed peat has a water-regulating action 4.4 times as great as that of old fall-plowed fields. This fact is of importance in setting up pastures on sloping lands and in sowing grasses in soil-protecting crop rotations.

Conclusions

1. Chernozem soils are very permeable to water. In one hour 150 mm. of water was absorbed by continuously-tilled soils and up to 850 mm. by soils with a good structure (nonmowed steppe).

2. Both the amount and rate of water intake by soils with a good structure (nonmowed fected by the kind of agricultural practices in the field, of tillage of the soils, and by the prominence of structure and the looseness of the soil.

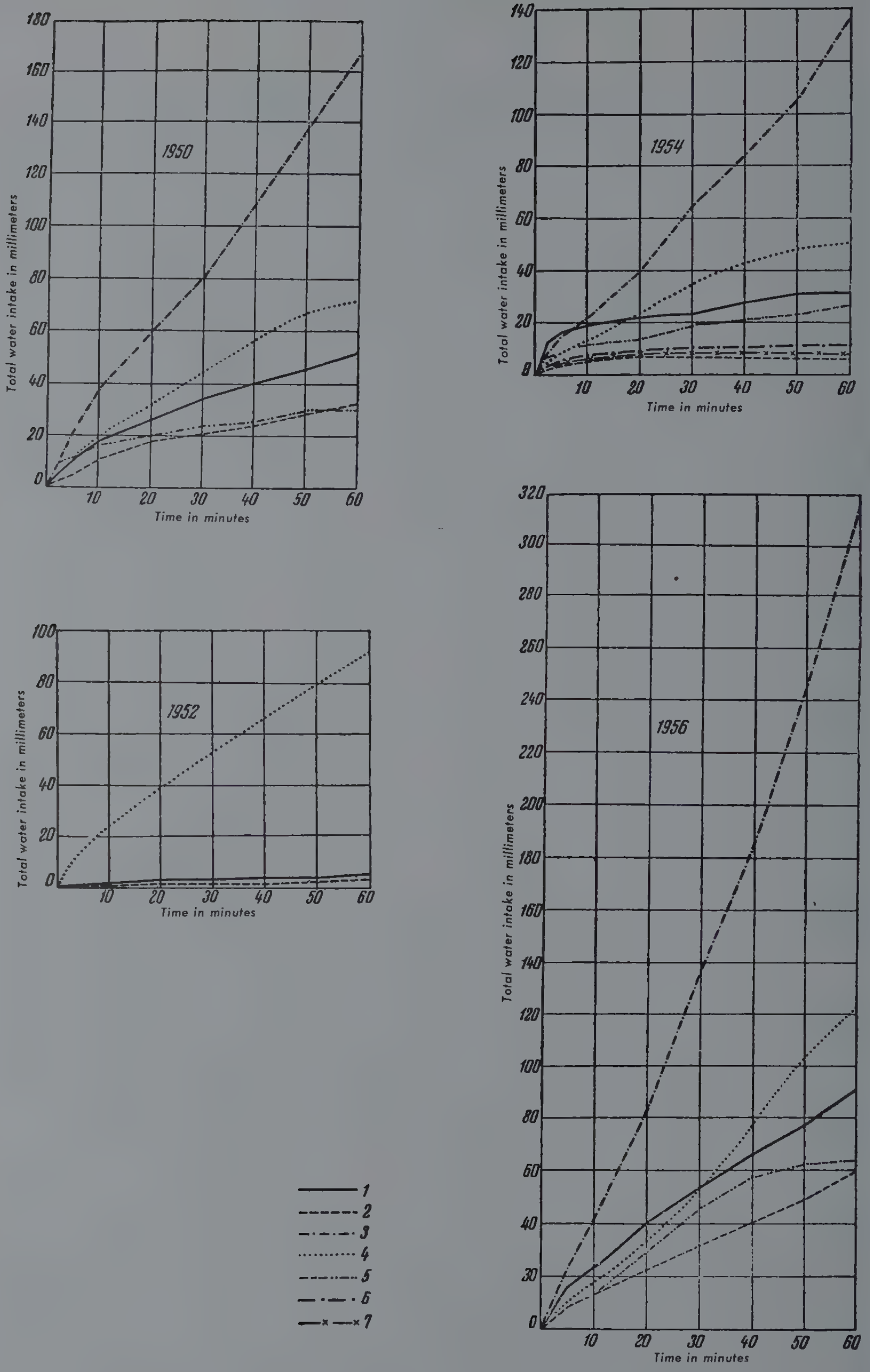

FIG. 4.—Entry of snowmelt in spring by the frozen soil of different farm lands. 1—Fall-plowed soil; 2—mowed steppe; 3—non-mowed steppe; 4—forest strip; 5—winter crop; 6—stubble; 7—grass.

The better the structure of the upper horizon of the soil, the higher the total amount and rate of water intake.

3. The soil moisture (or lack of it) also exerts an effect on water intake, but this influence is usually more significant in the water intake by frozen soil than in that by thawed soil in summer.

4. The lowest intake rate in summer in our experiments was observed on rotation pasture and fallow—both continuously-plowed fields. Pasturing cattle and excessive plowing of the land causes puddling of the soil and a decrease in its permeability to water. Grass sowings restore the soil structure and a sharp increase in its permeability to water when the grass is plowed up.

5. A crust of ice on the soil surface in winter considerably decreases the water intake on all farm lands, including fall-plowed land.

6. Since the water intake by the soil depends strongly on the agricultural engineering practices on the fields, it is thus possible by proper soil tillage to achieve a considerable increase in moisture on the fields by absorption of the spring snowmelt.

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SOME QUESTIONS ON GENESIS OF CHESTNUT SOILS[1] IN THE SEMIHUMID SUBTROPICS OF THE EASTERN TRANSCAUCASUS[2]

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THE chestnut soils in the semihumid subtropics of the eastern Transcaucasus, which are widespread chiefly in the Astrakhan-Bazanskii Administrative District of the Azerbaidzhan SSR, have been studied by many investigators (1, 2, 3, 7, 13, 16) but their genesis has not yet been satisfactorily explained.

Geomorphologically this area is divided into a series of marine terraces outstanding among which is the "zero" terrace (an area of wide distribution of chestnut soils) which is located at an absolute altitude of 0 to 50 meters and which reflects fluctuations in the level of the Caspian Sea during the epoch of the Khvalinsk transgression. The zero terrace has the character of a sloping plain. In the littoral lowland there are terraces below sea level which are related to the post-Khvalinsk epoch.

The transgressions of the Caspian Sea during the Quaternary Period salinized soil-forming and underlying parent material. Regions lying below sea level are related to the marine type of salinity (predominantly chloride-sulfate) (3, 16). Other types of salt accumulation besides the marine (4, 9) are also found.

The soils have been formed on colluvial, slightly carbonate clay loams and clays underlain by marine deposits. The latter are represented by cinnamon-brownish, residually salted clay with infrequent fragments of shells and with cinnamon-brownish clayey sand.

The region in which chestnut soils are widespread is characterized by a semi-humid subtropical climate. The annual precipitation varie from 300 or 400 mm. in the north to 500 mm. i the south. Most of the precipitation falls durin the fall and winter. The mean annual temperature is 15° C. (17, 18).

The definitive factors in the nature of th plant cover of this region of Azerbaidzhan include not only the climate, but also the degre of primary salinity of the soils and of the paren material. Salinization of the parent material b water from the Caspian Sea during the Quaternary and present periods caused, and is stil causing, definite ecological conditions for plan communities and for formation of soil an plant cover in the semihumid subtropics of th eastern Transcaucasus.

In a westerly direction from the Caspian Sea as the elevation and desalting of the area increase, the following pattern is observed in th succession of vegetation types (5, 6): 1) halophytic semidesert; 2) *Artemisia*-halophytic semidesert; 3) *Artemisia* semidesert, which graduall goes over into grassy-mixed herbaceous steppe

Our ideas on genesis of chestnut soils in th semihumid subtropics of the eastern Transcaucasus are summarized in general terms as follows: Considerable masses of water-soluble salts deposited by the sea which receded after th Khvalinsk transgression salinized the parent material and caused broad development of salin soils. With mineralized ground water at a high level, evaporation and biological accumulation of salts by halophytes caused the formation of solonchaks similar to those very common at present in the maritime regions of the eastern Transcaucasus. When the Caspian Sea receded with a resulting decrease in the ground water level, the solonchaks were desalinized and gradually evolved into solonetz soils, particularly "structured solonetzes" (13).

These were located at the point of contact between solonchaks and chestnut solonized soils. Preobrazhenskii wrote: "It may be assumed that solonetzes are relicts associated with some previous salinization of the seashore."

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[1] The author used the earlier concept of the systematic assignment of the soils he describes as the chestnut group although he notes their distinguishing characteristics by introducing the supplementary qualification "of the humid subtropics" into the designation.

This article reveals that the soils described belong to the type now called "cinnamon brown" (korichenevyi).—Russian Ed.

[2] This work was done under the direction of Professor F. Ya. Gavrilyuk, D. Agr.

Plant cover changed with changed ecological conditions caused by desalinization of the upper horizons of the solonchaks. The *Artemisia* population, which had been displaced by the halophytes, reappeared on solonchak-solonetz and solonetz soils. The grassy-mixed herbaceous vegetation of the steppe appeared with further desalinization. These plants accumulated calcium (8, 10) and solonetzes became chestnut solonized soils. We discovered the genetic relationship between soil and the Caspian Sea regression (with absolute age of the area) on the soil map of the Lenkoran Mugan steppe, Astrakhan-Bazarsk district, compiled by Preobrazhenskii in 1935. It is possible to trace on the map all the stages of solonchak-solonetz soil formation from the salinized "subsoils" to the chestnut solonized and desalinized soils.

Salinized subsoils, solonchaks, solonetz-solonchak soils, structured solonetzes, chestnut solonized soils, chestnut desalinized soils: this is generally how the soils develop with increases in elevation and desalinization.

The pronounced initial solonization of the chestnut soils in the semihumid subtropics of the eastern Transcaucasus cause the following morphologic peculiarities: pronounced vertical cracking; fusion and compaction of horizons B_1 and B_2; extensive elongation of humus horizons that extend down 70 to 100 cm. and further (Table 1)—presence in the profile of humus tongues.

Also evidence of the previous solonetz stage are: concentration of clay particles in the middle portion of the profile (Table 2); and the loss of sesquioxides (Table 3), chiefly aluminum, as a result of its great mobility at $pH > 8$ (12, 14).

According to Rozanov (15), a distinguishing characteristic of all the soils of the Kura-Araksinsk lowland is a high clay content of the profile in general and of its middle portion in particular. Particle-size analysis of a weakly solonized chestnut soil confirms this (Table 2). Table 2 shows an increased content of clay particles (<0.001 mm.) in the middle portion of the soil profile as compared to the upper horizon and parent material. The high clay content in the middle portion is related not only to illuviation during solonization and to internal profile weathering (15), but also to the internal profile movement of colloids which took place when the soil solution was alkaline sometime in the past. The alkaline reaction of the solonetz soil solution, rising above the isoelectric points of the iron and aluminum hydroxides (iron and aluminum sesquioxides are isoelectric at pH 7.1 and 8.1 respectively [Mattson (11)]), created favorable conditions for the movement of peptized, negatively charged colloids.

TABLE 1

Content of humus and carbonates in weakly solonized chestnut soils (in percent)

Horizon and depth of sample, cm.		Humus by Tyurin's method	CO_2	$CaCO_3$ on basis of CO_2
A	0–20	3.46	none	none
B_1	45–50	2.62	0.14	0.31
B_2	65–70	1.76	1.47	3.33
C	80–85	0.87	5.76	13.07
D	145–150	0.34	4.18	9.49

TABLE 2

Particle-size analysis of weakly solonized chestnut soil by N. A. Kachinskii's method (as percent of dry soil weight)

Horizon and depth of sample, cm.		Hygroscopic moisture, %	Fractions in millimeters						Total <0.01
			1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	< 0.001	
A	0–20	5.78	1.95	22.05	17.64	12.89	9.78	35.69	58.36
B_1	45-50	6.02	1.84	9.26	18.70	19.84	6.53	48.83	70.21
B_2	65–70	5.99	1.92	17.99	17.38	11.42	9.37	41.92	62.71
C	80–85	4.83	3.79	16.31	18.00	10.90	10.26	40.74	61.90
D	145–150	4.82	3.18	16.41	20.15	9.56	14.53	36.17	60.26

The negatively charged colloids of aluminum, which reached soils under weakly alkaline reaction via capillary rise, acquired a positive charge and mutually coagulated with the negatively charged colloids of the humus, silicic acid and iron hydroxides. V. V. Akimtsev (2) and A. S. Preobrazhenskii (13) explained that solodization of chestnut soils in the semihumid subtropics of the eastern Transcaucasus is definitely related to the solonetz stage of soil formation. This explains the high concentration of clay content in the middle portion of the profile in chestnut soils.

Table 3 shows a narrow molecular ratio of silicic acid to the sesquioxides in horizon D, a special characteristic of subtropical weathering of parent material in the Azerbaidzhan region. The accumulation of sesquioxides in the middle hori-

TABLE 3

Complete analysis of weakly solonized chestnut soil as percent of an ignited carbonate-free sample

Horizon and depth of sample, cm.		SiO_2	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Molecular ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$
A	0–20	66.50	26.63	7.16	19.45	2.39	1.76	0.57	5.21
B_1	45–50	62.30	31.06	7.65	23.39	1.33	1.87	0.34	3.66
B_2	65–70	64.95	28.66	7.12	21.51	2.07	1.96	0.52	4.23
C	80–85	65.45	28.56	7.13	21.40	1.23	2.86	0.75	4.50
D	145–150	64.83	26.95	7.78	19.14	1.20	2.98	1.59	4.60

TABLE 4

Analysis of an aqueous extract of weakly solonized chestnut soil in percent (numerator) and milliequivalents (denominator)

Depth of sample, cm.	Dry residue, %	Residue from ignition, %	Alkalinity		Cl^-	$SO_4^{=}$	Ca^{++}	Mg^{++}	$Na^+ + K^+$ by difference
			$CO_3^{=}$	HCO_3^-					
0–20	0.14	0.11	none	$\frac{0.018}{0.30}$	$\frac{0.002}{0.08}$	$\frac{0.058}{1.21}$	$\frac{0.021}{1.05}$	$\frac{0.003}{0.33}$	$\frac{0.005}{0.21}$
65–70	0.19	0.15	none	$\frac{0.073}{1.17}$	$\frac{0.003}{0.09}$	$\frac{0.040}{0.85}$	$\frac{0.020}{1.00}$	$\frac{0.007}{0.73}$	$\frac{0.008}{0.38}$
145–150	0.43	0.45	none	$\frac{0.065}{1.11}$	$\frac{0.020}{0.59}$	$\frac{0.211}{4.39}$	$\frac{0.046}{2.39}$	$\frac{0.016}{1.35}$	$\frac{0.053}{2.31}$

TABLE 5

Composition of exchange cations in soils by K. K. Gedroits' method

Soil	Depth of sample, cm.	Meq./100 gm. on absolutely dry soil			Total Ca + Mg + Na	As % of total			$\frac{Ca}{Mg}$
		Ca	Mg	Na		Ca	Mg	Na	
Weakly solonized chestnut	0–20	24.2	7.2	1.2	32.6	75.0	21.3	3.7	3.5
	45–50	21.1	15.3	2.4	38.8	53.8	40.0	6.2	1.3
	65–70	18.0	16.3	3.2	37.5	48.8	43.6	8.6	1.1
Desalinized chestnut	0–20	25.4	6.2	0.8	32.4	78.4	19.2	2.5	3.6
	45–50	24.1	10.0	1.5	35.5	67.6	28.3	4.1	3.5
	65–70	23.0	10.2	1.8	35.0	65.8	29.1	5.14	2.2

zons may be explained both by illuviation with solonization and solodization, and also by the internal profile movement of colloids when the soil solution is alkaline.

The slightly decreased content of SiO_2 in horizon B_1 is evidently inherited from the solonetz stage. The increase in CaO and SO_3 in the upper horizon, in comparison with their content in the middle portion of the profile, may be explained by the biological accumulation of these elements.

The comparatively high alkalinity in the middle portion of the profile, the residual solonchak tendency (Table 4), and the increase in adsorbed sodium with depth (Table 5), are all traces of prolonged desalinization and removal of solonetz in previous stages. Also extremely significant in this respect is the composition of exchangeable cations and the manner in which they change during the course of desolonization under the influence of the biological accumulation of calcium.

A comparison of weakly solonized chestnut soils with the desolonized chestnut soils replacing them shows that in the latter there is an increase in the amount of exchangeable calcium and a decrease in the content of exchangeable magnesium and sodium (Table 5). A distinguishing characteristic of the adsorbed cations of weakly solonized chestnut soils is the narrow ratio of calcium to magnesium. The amount of magnesium is very high and increases even more with depth. The high content of adsorbed magnesium in the lower horizons can hardly be explained by the solodization of these soils (2, 13); although it would explain that as a rule the maximum content of adsorbed magnesium is observed in the lower portion of the profile which has been unaffected, or only negligibly affected, by the solodization process.

The large amount of adsorbed magnesium in the profile of chestnut soils in the semihumid subtropics of eastern Transcaucasus must be considered a relict of marine salinization and the solonetz stage.

Conclusions

1. The chestnut soils in the semihumid subtropics of the eastern Transcaucasus passed through a solonchak-solonetz stage of soil formation.

2. The *Artemisia* vegetation was replaced by

grassy-mixed herbaceous steppe type which ccumulated calcium, thereby developing soloetzes into chestnut soils.

3. The uniqueness of chestnut soils in the emihumid subtropics of the eastern Transcaucaus, characterized by extensive deepening of the umus horizons, pronounced vertical cracking nd cementation and accumulation of clay in the niddle portion of the profile, is a result of the olonchak-solonetz stage of soil formation.

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SOIL COMPLEXES OF THE WEST BANK OF THE IRTYSH IN THE SUBZONE OF DARK CHESTNUT SOILS

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This investigation was made in Pavlodar region on the west bank of the Irtysh river between 51° 40′ to 53° N. and 74° to 77° W. of Greenwich in the subzone of dark-chestnut soils.

In this area the dominant climate is dry and continental, having long, cold winters with little snow, and hot summers. The terrain was formed in the Quaternary by the wandering of the Irtysh and is essentially an alluvial plain hardly touched by destruction (4, 5, 6, 7, 9). Quaternary alluvial deposits, highly variable in particle sizes, cover the Tertiary clays. The ground water is distinguished by its great variety in depth, manner of occurrence, and mineral content. The drainage system is poorly developed. The basic plant cover is feather grass-steppe fescue and herbaceous-*Artemisia* associations and their complexes with solonetz, meadow and halophyte vegetation.

Because of the tropical flora found in Tertiary quartzites, we believe that in preglacial periods tropical soils were widespread here. But the present soil cover of the west bank of the Irtysh is distinguished by its great variation and complexity. Dark-chestnut soil, present as a background, occupies only the highest parts of the watersheds, while about half the area is taken up by soil complexes. Hydromorphic, polymorphic and xeromorphic complexes are distinguished.

Hydromorphic (Lowland) Soil Complexes. The components of hydromorphic complexes, associated with an excess of subsoil moisture, are solonchaks, meadow solonchaks, and solonchak-solonetz soils. A high content of water-soluble salts and a negligible humus content characterize these soils (Table 1). The adsorbing complex of solonetz-solonchaks contains considerable amounts of adsorbed sodium.

Two species of complexes are found in this area: solonchak-type and meadow-solonchak-type. More widely distributed is the solonchak complex, occurring in the lowest parts of lake depressions with pronounced microrelief. Chloride-sulfate and solonetz-solonchaks are its components. Solonchaks located in microdepressions have a constant influx of salts from ground wat reaching them via capillarity, while the sol nized state is created periodically in the solonet solonchaks located in microdepressions.

Meadow-solonchak complexes are usual formed along the peripheries of lake depressio and in large basins. A decisive role in their fo mation is the varying degree of salinization the ground water and the intensive surfa moistening. The components include solonchak solonetz-solonchaks, and meadow solonchaks. characteristic feature of the latter is the in creased salt content in the upper horizons. Th meadow-bog complex is negligible and is foun in spots where water emerges from a porou stratum. Bog soils occur here in depression along with meadow soils. Solonchak soils occup higher relief. If the erosion level goes down thes complexes are probably transformed into thos described previously.

Polymorphic Soil Complexes. As a resu of uneven relief, texture, and other factors, som components of polymorphic complexes are unde conditions of constant subsoil moisture. In othe the subsoil is periodically moistened with sali ized ground water. Still others are under "pl kornyi" [meaning unknown] circumstances, an some receive moisture from fresh ground wate There are also meadow soils, meadow solonetze and steppe solonchak-solonetzes in the poly morphic types of complexes.

The chemical composition of these soils (Tabl 1) shows their radical difference from those de scribed previously. Noticeable immediately i the negligible content of soluble salts, relate directly to the absence of a ground water sourc for them. The humus content increases con siderably, especially in meadow soils and meado solonetzes. Steppe solonetzes are characterize by the presence of adsorbed sodium, which i of small content in meadow solonized solonchak

The polymorphic type of complex formatio includes the solonchak-solonetz and meadow solonetz complexes.

The solonchak-solonetz complexes are com posed of solonchaks formed in microdepressio nd of solonetz-solonchaks formed on microele-ations. The periphery and highest-lying tracts re covered by solonchak steppe solonetzes ocurring usually around the peripheries of lake epressions and on the lower third of gentle opes. Slight but broad steppe depressions are overed by meadow-solonetz complexes comosed of meadow solonchaks, meadow solonetzes, nd meadow soils. It is possible to trace the disribution of the components according to the icroelements of the relief. In lower-lying places ith an influx of ground water, meadow solonhaks occur. The highest-lying places, usually ith surface moisture, have meadow solonetz nd meadow soils.

These complexes are two branches of the evotionary process—steppe and meadow formaon—and their components are divided by the ages of the process.

Xeromorphic Soil Complexes. The xeroorphic type of complex formation is wideread on the west bank of the Irtysh Foreland. hese complexes usually consist of two comonents: steppe solonetzes, and dark-chestnut oils with different degrees of solonization. Two pes of complex formation are distinguished: olonetz and solonetz-steppe. Both components the complexes in the same soils, differ only their quantitative ratio and in the degree which the solonizing process is found.

As a rule solonetz complexes cover the middle ird of gentle slopes. The distribution of these mponents is affected by hardly noticeable icrodepressions in which solonetzes are formed. he complexes are usually made up of crusted medium columnar steppe solonetzes and darkestnut solonized soils. Solonetzes exist in these mplexes to the extent of 30 to 50% and more.

Solonetz-steppe complexes are composed of eeply columnar steppe solonetzes and darkestnut solonized or weakly solonized soils. hey are formed on the upper third of the slopes. olonetzes cover a varied portion of this area, sually not more than 30% and mostly 10 to 0%, but small isolated spots of solonetzes are ncountered even on watersheds and around the lges of mountain ranges.

Evolution of Complexes. It is possible to e a regular pattern in the change of morphoenetic structure and chemical composition in omplex soils of different types and species. First e find desalinization processes taking place adually in the transition from hydromorphic complexes to xeromorphic complexes. A quantitative decrease in salts (the Cl/SO_4 ratio) is clearly traced, along with qualitative changes (Tables 1 and 2). This suggests an increase in the rate of desalinization in polymorphic and especially in xeromorphic complexes. Even in the initial stages of desalinization in hydromorphic complexes, soil solonization occurred in one case, and solonization and simultaneous meadow formation took place in another. In the initial stage of solonization the $Cl^-/SO_4^=$ ratio increases abruptly, evidently because of the increase in alkalinity. Conditions are created for the introduction of Na^+ into the adsorbed complex of the soil. Simultaneously with desalinization there is accumulation of organic matter in the upper part of the soil and differentiation of the profile into clearly distinguished genetic horizons.

In soils of the polymorphic type of complexes the two processes begun earlier—meadow formation and solonization—go deeper with further desalinization. Depending on the circumstances there is formation of meadow solonetzes and meadow soils (excessive surface moistening and moistening with fresh ground water) or of meadow-steppe and steppe solonetzes. In these soils further accumulation of humus takes place and the profile takes on the appearance of the latter two. In xeromorphic complexes the soils are practically desalinized on the one hand, while on the other there is progressive development of steppe characteristics in the solonetzes, resulting in the formation of zonal dark-chestnut soils.

We see the transformation of soil complexes as follows (see Figure). The abundant moisture supply in this location, resulting from the wandering of the ancient Irtysh supported by a glacier in the upper Quaternary, is established in a number of paleogeographic and geological papers (1, 2, 4, 5, 7, 8, 9). We assume that the meadow-bog stage of soil formation was dominant at this time. With the advent of the xerothermal phase, the meadow-bog stage was replaced here by a solonchak stage (5). Later, along with a smoothing out of the relief, a lowering of the erosion base and a certain cooling of the climate, there was general solonetz formation and then gradual steppe formation in the soil cover. Most commonly there was meadow formation on the meadow-solonetz and meadow-solonchak soils. As a result, dark-chestnut soils developed under xeromorphic conditions and meadow soils under hydromorphic conditions.

TABLE 1

Chemical analyses of components of the hydromorphic and polymorphic types of complexes[a]

Depth of sample, cm.	Total humus, %	Total nitrogen, %	C/N	Total P_2O_5, %	Carbonate CO_2, %	Cation exchange capacity meq. per 100 gm.	Adsorbed cations as % of capacity		pH of water	Percentage content in water extract of:								
							Ca^{++} + Mg^{++}	Na^+		Total alkalinity HCO_3^-	Cl^-	$SO_4^{=}$	Ca^{++}	Mg^{++}	Na^+	Solid residue, %	$Cl^-/SO_4^{=}$	Gy sur %
Section 168. Chloride-sulfate solonchak																		
0–10	ND[b]	ND	ND	ND	0.38	ND	ND		6.4	0.0366	0.0816	0.1545	0.0196	0.0085	0.1021	0.395	0.7	0.
15–20	ND	ND	ND	ND	0.46	ND	ND		6.5	0.0488	0.1846	0.3360	0.0420	0.0110	0.2185	0.837	0.7	2.
70–80	ND	ND	ND	ND	1.88	ND	ND		7.0	0.0488	0.1597	0.5069	0.1280	0.0195	0.1807	1.050	0.4	16.
140–150	ND	ND	ND	ND	2.86	ND	ND		6.9	0.0427	0.2840	0.1411	0.0504	0.0068	0.1373	0.720	2.7	1.
Section 104. Meadow solonchak																		
0–4	ND	ND	ND	ND	3.80	ND	ND		6.4	0.0427	0.1207	1.7136	0.2520	0.0170	0.5934	2.750	0.1	26.
20–30	ND	ND	ND	ND	1.84	ND	ND		6.7	0.0488	0.4795	0.2611	0.3072	0.0078	0.0850	1.200	2.4	35.
110–120	ND	ND	ND	ND	6.40	ND	ND		6.9	0.0427	0.1988	0.4704	0.1260	0.0256	0.1770	1.080	0.6	24.
Section 26. Solonetz solonchak																		
0–10	2.84	0.15	10.9	0.11	2.2	10.9	72.3	27.7	7.3	0.0610	0.0532	0.0258	0.0993	0.0043	0.0492	0.315	2.8	N
20–30	2.20	0.12	10.6	0.10	4.5	10.6	76.1	23.9	7.5	0.0732	0.5325	0.2371	0.0720	0.0109	0.3827	1.295	3.0	N
70–80	0.72	ND	ND	ND	3.0	ND	ND		7.0	0.0366	0.2840	0.2956	0.0656	0.0324	0.1913	0.910	1.3	N
100–110	0.52	ND	ND	ND	2.94	ND	ND		7.1	0.0366	0.3479	0.2688	0.0364	0.0256	0.3003	1.000	1.7	N
150–160	none	ND	ND	ND	2.84	ND	ND		7.1	0.0732	0.2662	0.3456	0.0704	0.0039	0.2773	1.110	1.0	N
Section 100. Solodized Meadow solonetz																		
4–14	5.04	0.26	11.2	0.13	0.03	16.6	94.5	5.5	6.7	0.0244	0.0021	0.0201	0.0056	0.0034	0.0073	0.068	0.1	N
18–26	4.30	0.20	12.5	0.12	0.22	9.0	95.6	4.4	6.8	0.0487	0.0060	0.0203	0.0112	0.0048	0.0112	0.106	0.6	N
36–46	1.57	ND	ND	ND	0.50	ND	ND	ND	7.0	0.0366	0.0028	0.0471	0.0084	0.0068	0.0156	0.122	0.1	N
62–72	1.05	ND	ND	ND	3.34	ND	ND	ND	7.1	0.0854	0.0064	0.0067	0.0112	0.0051	0.0170	0.140	1.3	N
106–116	0.14	ND	ND	ND	5.68	ND	ND	ND	7.9	0.0854	0.0482	0.0806	0.0140	0.0034	0.0795	0.314	0.8	N

Note: Soda (CO_3) was absent from all the samples analyzed.

[a] The analyses were carried out in 1954 in the chemical laboratory of the Geological office of t Ministry of Building Materials, Kazakh SSR, at the request of the Ministry of State Farms, Kaza SSR.

[b] ND = not determined

The diagram cannot encompass all the variable conditions. However, in our opinion it is accurate enough in reflecting the general evolution of the soil cover of this area and is frequently applicable to the individual soil-forming process.

Distribution of Soil Complexes. In this territory different types of soil complexes are developing under suitable conditions of relief, ground water, and so forth. We distinguished two subregions: the subregion of hydromorphic and polymorphic complexes, which occupy the western and northwestern part along the chain of salt lakes (Karasor-Dzhamantuz, Maldybaituz and others), and the subregion of xeromorphic complexes and soils, east of the fir subregion extending to the Irtysh river valle All the area described in this paper should separated into a special, independent Irty Foreland region on the basis of its special co ditions of relief, parent material, and soil cove

Agricultural Utilization of Regions with Complex Soil Cover

In considering the utilization of this area should note the low natural fertility caused the coarse texture of the zonal dark-chestn soils. They have unfavorable hydrophysical pro erties because a water-stable structure is almo completely lacking. As a result, there is a lo

TABLE 2

Chemical analyses of components of the xeromorphic types of complexes

Depth of sample, cm.	Total humus, %	Total nitrogen, %	C/N	Total P_2O_5 %	Carbonate CO_2, %	Cation exchange capacity me. per 100 g.	Adsorbed cations as % of capacity		pH of water	Percentage content in water extract of:								
							Ca^{++} + Mg^{++}	Na^+		Total alkalinity HCO_3^-	Cl^-	$SO_4^=$	Ca^{++}	Mg^{++}	Na^+	Solid residue	$Cl^-/SO_4^=$	Gypsum %
Section 550. Dark-chestnut slightly solonetz soil																		
0–10	3.99	0.20	11.5	0.13	0.28	9.8	97.9	2.1	6.9	0.0427	0.0021	0.0201	0.0084	0.0051	0.0078	0.095	0.1	ND
12–22	1.59	1.10	9.2	0.11	0.17	11.5	92.2	7.8	7.0	0.0366	0.0053	0.0172	0.0108	0.0043	0.0048	0.080	0.4	ND
28–38	1.35	ND[a]	ND	ND	0.20	ND	ND	ND	6.8	0.0244	0.0021	0.0134	0.0080	0.0034	0.0016	0.056	0.2	ND
50–60	0.76	ND	ND	ND	1.08	ND	ND	ND	6.7	0.0366	0.0042	0.0268	0.0140	0.0034	0.0069	0.093	0.2	ND
80–90	0.67	ND	ND	ND	8.90	ND	ND	ND	7.5	0.1098	0.0021	0.0134	0.0280	0.0034	0.0105	0.170	0.2	ND
30–140	0.36	ND	ND	ND	0.30	ND	ND	ND	7.0	0.0488	0.0053	0.0259	0.0144	0.0065	0.0053	0.117	0.3	ND
Section 447. Dark-chestnut solonetz soil																		
0–10	3.91	0.20	11.5	0.11	0.12	6.7	94.1	5.9	7.0	0.0244	0.0021	0.0034	0.0056	0.0024	0.0011	0.040	0.9	ND
20–30	1.83	0.10	10.5	0.11	1.80	12.1	89.3	10.7	7.1	0.0488	0.0053	0.0134	0.0124	0.0041	0.0057	0.090	0.5	ND
45–55	0.60	ND	ND	ND	3.34	ND	ND	ND	7.4	0.0732	0.0071	0.0172	0.0252	0.0043	0.0032	0.130	0.5	ND
75–85	0.40	ND	ND	ND	2.76	ND	ND	ND	7.4	0.0488	0.0213	0.0134	0.0168	0.0051	0.0096	0.125	2.1	ND
90–100	0.15	ND	ND	ND	2.82	ND	ND	ND	7.3	—	ND	ND	ND	ND	ND	ND	ND	ND
50–160	0.07	ND	ND	ND	3.00	ND	ND	ND	7.3	0.0549	0.0355	0.0691	0.0180	0.0065	0.0437	0.230	0.7	ND
Section 276. Crusted steppe solonetz																		
0–10	1.89	0.10	10.9	0.09	0.04	7.5	96.0	4.0	7.1	0.0488	0.0443	0.0259	0.0144	0.0022	0.0388	0.175	2.3	0.42
15–25	1.79	0.09	11.5	0.08	1.20	25.5	73.4	26.6	7.3	0.0610	0.1242	0.0921	0.0256	0.0039	0.1108	0.418	1.3	12.02
45–55	0.87	ND	ND	ND	1.82	ND	ND	ND	7.4	0.0366	0.1066	0.1344	0.0366	0.0085	0.0924	0.415	1.0	3.40
70–80	0.60	ND	ND	ND	3.20	ND	ND	ND	7.2	0.0488	0.0710	0.5280	0.0972	0.0329	0.1435	0.930	0.2	1.15
10–120	0.40	ND	ND	ND	0.66	ND	ND	ND	7.1	0.0488	0.0266	0.0043	0.0036	0.0065	0.0211	0.112	8.3	0.28
90–200	0.22	ND	ND	ND	0.52	ND	ND	ND	6.9	0.0488	0.0220	0.0518	0.0216	0.0043	0.0243	0.184	0.6	0.21
Section 261. Deeply columnar steppe solonetz																		
0–10	3.73	0.20	10.9	0.11	0.20	7.8	93.6	6.4	6.6	0.0305	0.0021	0.0201	0.0084	0.0051	0.0032	0.075	0.1	0.10
23–35	1.51	0.10	11.5	0.10	0.24	20.3	75.3	24.7	6.8	0.0427	0.1704	0.0470	0.0168	0.0034	0.1232	0.405	4.9	0.60
45–55	0.63	ND	ND	ND	2.77	ND	ND	ND	7.3	0.0610	0.1331	0.3196	0.0612	0.0220	0.1506	0.750	0.6	1.02
60–70	0.55	ND	ND	ND	3.00	ND	ND	ND	7.2	0.0488	0.0887	0.2678	0.0540	0.0222	0.1002	0.582	0.4	3.10
80–90	0.46	ND	ND	ND	0.14	ND	ND	ND	7.3	0.0610	0.0266	0.0172	0.0144	0.0043	0.0237	0.155	2.1	0.28
10–120	0.10	ND	ND	ND	0.40	ND	ND	ND	7.1	0.0488	0.0266	0.0086	0.0108	0.0043	0.0191	0.120	4.2	0.14

Note: Soda was absent from all the samples analyzed.

[a] ND = not determined.

ontent of humus and nutrients (Table 2). The olonetz soils are still less fertile. This considrably complicates improvement of this region. n addition to measures to eliminate the soloietz properties, other measures are needed to inrease the natural soil fertility.

Up to the present time this region has not ttracted the attention of investigators, which xplains the absence in the literature of infornation on its soil cover (except for certain sureys). No one has studied the question of improving its solonetz soils. However, in recent years there has been large-scale soil mapping in which the author of this article took part. For successful utilization of the west bank of the Irtysh in the dark-chestnut subzone, we must make studies of the soils from many aspects and set up experiments to show which methods of improvement are most effective.

Conclusions

1. The west bank of the Irtysh in the subzone of dark-chestnut soils has a series of specific characteristics entitling it to be set apart

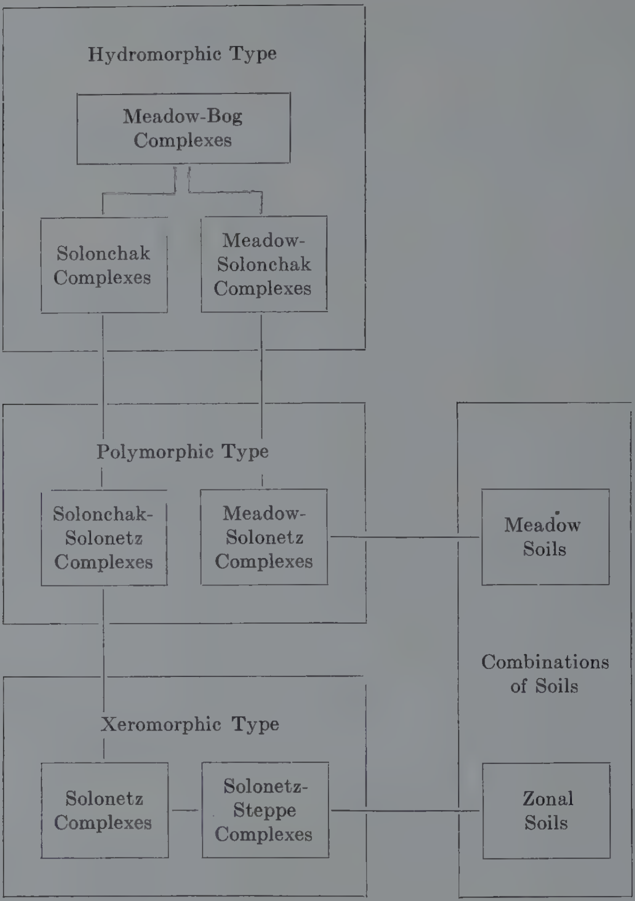

FIG. 1. Transformation of soil complexes

in an independent Irtysh Foreland region. The characteristic traits of this region are the predominance of coarse textured soils and the presence of complexes occupying up to 50% of the soils.

2. Among the soil complexes of this region, as judged by the predominant types of the soil-forming process in the components, hydromorphic, polymorphic, and xeromorphic types of complexes are distinguished.

3. The evolution of the soil cover is in a regular series: meadow-bog, solonchak and solonetz, with later steppe formation.

4. To utilize this region for sowing grains, work must be undertaken to determine the most effective methods of improving the solonetzes.

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EFFECT OF LIMING ON PHYSICOCHEMICAL AND PHYSICAL SOIL PROPERTIES IN THE SOUTHERN ESTONIAN SSR

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From 1947 to 1949 the Soil Science Laboratory of the Institute of Plant Culture, Academy of Sciences, Estonian SSR, set up a number of field experiments on collective and state farms in the southern districts of the republic to study the effect, both on the soil and on the yield of farm crops, of different quantities of lime (from one quarter to double the amount of hydrolytic acidity). In most of the experiments burned lime was used, and in some slaked lime and tufa. Lime fertilizers were applied to fields in fallow in two applications: half of the amount was applied in summer and plowed in with simultaneous application of organic fertilizers; the other half was applied under a harrow or cultivator following replowing. Each of these treatments was replicated four times. The area of each plat in all the experiments was 100 square meters.

Physicochemical Changes of Soil Properties After Liming

Effect of Liming on Adsorbing Complex. The results of liming were evaluated by the change in hydrolytic acidity of the soil; by the total adsorbed cations (by Kappen's method [4]); by the cation exchange capacity (T) and degree of soil saturation by cations calculated according to the total adsorbed cations; and by the change in the pH as determined electrometrically with aquinhydrone electrode in a 1 N KCl extract.

On all the experimental plats liming increased the pH value and decreased the hydrolytic acidity; the content of adsorbed cations in the adsorbing complex increased, as did the cation exchange capacity of the soils and their degree of saturation by cations. These changes were more pronounced on poor peat-medium- and peat-strongly-podzolic sandy, and sandy loams with a thin peat horizon (15 to 20 cm.) and slight humus content. Lesser changes occurred on cultivated peat-weakly- and peat-medium-podzolic coarse clay loams having a fairly thick peat horizon (25 to 30 cm.) which contained a corresponding amount of humus. See Table for results.

The decrease in hydrolytic acidity and the increase in the degree of soil saturation by cations reach fairly high values even when half of the unit quantity of lime fertilizer has been applied When unit and double quantities of lime fertilizers are applied, changes are less pronounced The total adsorbed cations and the cation exchange capacity increase more sharply only with double quantities of lime fertilizers.

The changes in the agricultural chemical indices are more pronounced on soils of sligh fertility ("Tee Kommunizmile" collective farm) than on cultivated ones ("Yulenurme" state farm).

Effect of Liming on the Content of Mobile Aluminum. Mobile aluminum was determined by Sokolov's method (2). Table 2 shows tha the greatest amount of mobile aluminum is contained in the slightly fertile peat-strongly- and peat-medium-podzolic sandy loams with a thin peat horizon and low humus content with a pH below 4.5. The content of mobile aluminum reaches 8.7 mg. per 100 g. on these nonlimed soils, but as soon as they are limed with half of the unit amount (as indicated by the hydrolytic acidity), the mobile aluminum disappears.

In other experiments the amount of aluminum on nonlimed plats was 1 to 2 mg. per 100 g. o soil. When one-eighth of the unit quantity o lime fertilizer was applied the amount of mobil aluminum decreased by half, and when half the unit quantity was applied it disappeared completely. Thus, the mobile aluminum may b eliminated by using half the quantity of lim fertilizer required by the hydrolytic acidity Smaller quantities considerably lower the content of available aluminum but do not eliminat it completely.

Effect of Liming on the Content of Available Phosphorus and Nitrates. The available phosphorus in the soil was determined i

TABLE 1

Changes with time in the agricultural chemical indices in slightly fertile and cultivated soils after liming

Agrochemical indices per 100 g. soil	Quantity of lime fertilizer (by hydrolytic acidity)[a]	Soil: Slightly fertile peat in strongly-podzolic sandy loam, A_1 horizon (18–23 cm.), "Tee Kommunizmile" collective farm[b]				Soil: Cultivated peat-weakly-podzolic coarse clay loam, A_1 horizon (25–33 cm.), "Yulenurme" state farm[b]			
		1950	1951	1952	1953	1950	1951	1952	1953
pH of KCl extract	0	4.5	4.3	4.5	4.4	4.8	4.6	4.8	4.8
	½	4.8	4.6	4.8	5.1	5.4	5.4	5.3	5.4
	1	5.3	5.7	5.5	5.9	5.9	5.7	5.6	5.6
	2	6.3	6.5	6.4	6.7	6.8	6.7	6.6	6.8
Hydrolytic acidity (H) in me.	0	4.2	4.6	4.5	4.7	3.5	3.8	3.8	3.6
	½	3.7	3.6	3.8	3.0	3.5	2.9	3.0	2.6
	1	3.2	2.6	3.0	2.1	3.6	2.4	2.7	2.2
	2	2.6	2.0	2.2	1.6	2.9	1.7	1.5	1.2
Adsorbed cations (S) in me.	0	3.5	4.6	4.7	3.2	4.7	5.9	5.8	5.1
	½	4.8	5.4	5.8	6.4	5.5	7.2	6.8	6.2
	1	6.2	8.7	8.2	9.1	6.4	8.2	8.6	7.8
	2	11.3	15.4	14.2	13.9	10.1	11.8	11.4	11.0
Cation exchange capacity (T) in me.	0	7.7	9.2	9.2	7.9	8.2	9.7	9.6	8.7
	½	8.5	9.0	9.6	9.5	9.0	10.1	9.8	8.8
	1	9.4	11.3	11.2	11.2	10.0	10.6	11.3	10.0
	2	13.9	17.4	16.4	15.5	13.0	13.5	12.9	12.2
Degree of cation saturation, %	0	45.4	48.8	51.4	40.0	57.1	60.4	60.6	58.9
	½	56.6	60.0	60.0	67.9	60.7	71.1	69.5	70.8
	1	65.5	76.6	71.9	81.1	64.1	75.0	75.2	78.3
	2	85.1	88.5	84.7	89.6	77.8	87.4	88 1	91.1

[a] The unit quantity (calculated for $CaCO_3$) on the "Yulenurme" state farm was 5 metric tons per hectare; on the "Tee Kommunizmile" collective farm it was 7.2 metric tons per hectare.

[b] Liming was carried out on the "Yulenurme" state farm in 1947 and on the "Tee Kommunizmile" collective farm in 1949.

1953 by A. T. Kirsanov's method.[1] The analyses showed that liming negligibly increased the amount of available phosphorus in the soil. The content of available phosphorus during the growing period varied. All the soils studied had a smaller quantity in the spring which increased toward fall.

With larger quantities of lime fertilizers, the amount of available phosphorus increased more abruptly than it did with smaller quantities (Table 3). For example, on the "Luun'ya" state farm the amount of available phosphorus rose 1.5 mg. per 100 g. of soil with double quantities of lime, whereas on the "Uus Elu" collective farm of the Tartu district the rise was 1 mg./100 g. of soil. However, the effect of using half quantities of lime fertilizer was, in most cases, an increase in available phosphorus of 0.5 mg./100 g. of soil.

The effect of liming on nitrogen relations was studied during the 1953 growing season. The nitrates were determined colorimetrically (3) in fresh soil samples (Table 4).

After liming, the amount of nitrates in the soil increases considerably and during almost the entire growing period remains higher than on nonlimed plats. But it varied somewhat during the summer. On May 20 the nitrate content of the soils in all the experiments was high; toward the middle of June it had decreased everywhere; and then toward the middle of July it increased, reaching its maximum. Toward fall the quantity of nitrates decreased again and the content on limed and nonlimed plats was almost the same.

TABLE 2

Effect of liming on mobile aluminum content

Location of experiment and description of soil	Quantity of lime fertilizer (by hydrolytic acidity)[a]	pH of KCl extract	Content of mobile aluminum in mg./100 g. soil		
			1950	1951	1952
V. I. Lenin collective farm, Vyru district. Peat-strongly-podzolic sandy loam on clay loam	0	4.2–4.3	8.7	8.0	6.6
	½	5.0–5.1	0.2	0.2	—
	1	5.5–5.9	—	0.2	—
"Tee Kommunizmile" collective farm, Tartu district. Peat-strongly- and medium-podzolic sandy loam on clay loam	0	4.3–4.5	5.3	3.9	3.0
	¼	4.7–4.8	1.8	0.4	0.6
	½	4.6–5.1	1.2	0.3	0.2
	1	5.3–5.9	0.2	—	—
I. V. Stalin collective farm, Pylva district. Peat-medium-podzolic sandy loam on clay loam	0	4.5–4.9	1.7	2.1	2.0
	⅛	4.6–5.1	0.8	0.9	0.8
	¼	4.7–5.0	0.5	0.3	0.3
	½	5.1–5.3	—	—	—
	1	5.5–6.0	—	—	—
"Yulenurme" state farm, Tartu district. Peat-weakly-podzolic sandy loam on clay loam	0	4.6–4.8	0.5	0.8	0.9
	½	5.3–5.4	0.2	0.2	0.1
	1	5.6–5.9	—	—	—

[a] The unit quantity (calculated for $CaCO_3$) on the V. I. Lenin collective farm was 8.4 metric tons per hectare, on "Tee Kommunizmile" it was 7.2, on I. V. Stalin it was 5.8 and on the "Yulenurme" state farm it was 5.0.

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[1] It must be noted that Kirsanov's method for determining available phosphates gives only a general estimate.

TABLE 3

Effect of liming on the content of available phosphorus

Location of experiment and description of soil	Crop	Quantity of lime fertilizer (by hydrolytic acidity)	Content of P_2O_5 per 100 g. soil			
			May 23, 1953		August 20, 1953	
			mg.	Effect of liming, mg.	mg.	Effect of liming, mg.
"Tee Kommunizmile" collective farm, Tartu district. Peat-strongly and medium podzolic sandy loam	Perennial grasses, 3rd year of use	0	1.9	—	3.7	—
		¼	2.2	+0.3	3.7	—
		½	1.9	—	4.2	+0.5
		1	2.5	+0.6	4.1	+0.4
		2	2.7	+0.8	4.5	+0.8
"Uus Elu" collective farm, Tartu district. Peat-medium podzolic sandy loam	Winter wheat	0	3.7	—	7.0	—
		¼[a]	4.6	+0.9	7.3	+0.3
		½	4.1	+0.4	7.5	+0.5
		1	4.5	+0.8	7.9	+0.9
		2	4.2	+0.5	8.0	+1.0
"Luun'ya" state farm, Tartu district. Peat-weakly podzolic coarse clay loam	Perennial grasses, 3rd year of use	0	2.9	—	8.0	—
		½[a]	3.8	+0.9	7.9	—
		1	3.7	+0.8	8.3	+0.3
		2	4.4	+1.5	8.4	+0.4

[a] The unit quantity (calculated for $CaCO_3$) on the "Uus Elu" collective farm was 5.9 metric tons per hectare; on the "Luun'ya" state farm it was 6.9 metric tons per hectare.

TABLE 4

Effect of liming on soil nitrates

Location of experiment and description of soil	Quantity of lime by hydrolytic acidity	NO_3 in mg. per kg. of soil Dates in 1953				
		May 20	June 16	July 16	Aug. 18	Sept. 27
"Luun'ya" state farm, Tartu district. Field under grass sod. Peat-weakly-podzolic coarse clay loam.	0	9.5	13.9	15.0	16.4	14.6
	½	11.4	11.8	23.1	13.6	14.9
	1	14.2	11.6	25.2	22.0	16.3
	2	16.7	10.8	31.0	26.4	14.5
"Tee Kommunizmile" collective farm, Tartu district. Field under grass sod. Peat-strongly- and medium-podzolic sandy loam	0	11.8	3.0	16.6	10.1	7.6
	¼	11.6	5.8	15.6	11.7	7.6
	½	13.6	8.4	20.8	11.8	9.6
	1	16.0	9.5	16.1	11.7	10.0
	2	17.2	15.4	22.8	19.7	10.0

Changes in Physical Properties of Soil with Liming

To determine the effect of liming on physical properties of soil, a study was made of bulk density and permeability of soil to water and air.

Changes in Intake Rate of Water with Liming. The intake rate of soil to water was studied in 1951 under field conditions using N. A. Kachinskii's method. These determinations showed that liming favorably affects intake rate of water, which indicates an improvement in the structural condition of the soil. On coarse clay loam the time required for absorption of a 20 cm. column of water on limed plats was 2.5 to 4.5 minutes less than on nonlimed plats. On coarse sandy loams and sandy soils the absorption time increased by 2 to 7 minutes, showing an increase in soil compactness.

On the "Mooste" state farm nonlimed plats of peat-medium- and strongly-podzolized clay loam, the adsorption time of a 20 cm. column of water was 31 minutes, 47 seconds, on plats with unit amount of liming it went down to 28 minutes, 24 seconds. On one of the collective farms in the Ryapina district on peat-strongly-podzolic sand and sandy loam the absorption time on nonlimed plats was 11:1, whereas on plats with unit liming they increased to 16:29.

Since N. A. Kachinskii's method is not particularly reliable under field conditions because of the small diameter of the tube, supplementary determinations were made of the intake rate of water using Boldyrev's apparatus, the cylinder of which had a cross-sectional area of 1/8 m². Three experiments on plats with perennial grasses in the second and third year of use (Table 5) were made. As a result of liming the intake rate of water doubled on the peat-weakly-podzolic clay loam of the "Luun'ya" state farm. In the other two experiments it also showed a strong increase.

Changes in Soil Permeability to Air with Liming. Soil permeability to air was determined by means of an FP-2U apparatus, which is used

TABLE 5

Effect of liming on soil permeability to air and water

Location of experiment and description of soil	Crop	1952			1953		
		Time for passage of 1 liter of air, sec.		Difference in seconds	Time to absorb 1 liter of water, sec.		Difference in seconds
		No lime	Unit amt. of lime		No lime	Unit amt. of lime	
"Mooste" state farm; peat-medium-podzolic coarse clay loam	Perennial grasses, 1st & 2nd year of use	209	165	−44	97	60	−37
"Luun'ya" state farm; peat-weakly-podzolic coarse clay loam	Perennial grasses, 2nd & 3rd year of use	192	112	−80	270	112	−158
"Kollino" state farm; peat-medium-podzolic coarse clay loam	Perennial grasses, 3rd year of use	458	205	−253	—	—	—
"Uus Elu" collective farm; peat-medium-podzolic sandy loam	Perennial grasses, 2nd year of use	191	83	−108	—	—	—
"Tee Kommunizmile" collective farm; peat-strongly-podzolic sandy loam	Perennial grasses, 2nd & 3rd year of use	198	174	−24	113	83	−30
I. V. Stalin collective farm; peat-medium-podzolic sandy loam	Perennial grasses, 1st year of use	114	120	+06	—	—	—
"Ruuza" state farm; peat-medium-podzolic sandy loam	Perennial grasses, 3rd year of use	154	165	+11	—	—	—

in metallurgy to determine permeability to gases. The author adapted the apparatus for work under field conditions with soils having an undisturbed structure.

Seven experiments were made in 1952 on plats with perennial grasses. See Table 5 for results.

A comparison of the changes in permeability to air with the changes to intake of water shows that these changes are similar in nature. Liming on fine-textured soils caused an increase in permeability to air, but on coarse soils it caused a decrease. The combined action of liming and perennial grasses, especially second and third year in grasses, increased the air permeability ("Kollino," "Uus Elu," "Ruuza").

Effect of Liming on Bulk Density. To determine the effect of liming on bulk density, soil samples were taken in 1951 and 1952 with cylinders having a volume of 1 liter; the bulk density was determined without disturbing structure. Table 6 shows that a unit quantity of lime fertilizer led to a reduction in the bulk density of a liter of soil by an average of 60 to 70 g. There was a further change when the lime fertilizer was combined with perennial grasses. However, the changes in bulk density were marked even without perennial grasses. For example, on one of the collective farms in the Ryapina district, the bulk density of a liter of peat-strongly-podzolic sandy soil from a field under oats decreased after the application of a unit quantity of lime fertilizer from 1281 to 1202 g., that is, by 79 g.

Effect of Liming Acid Soils on the Yield of Field Crops. Comparing the data on crops with the experimental material in Table 7, a definite ratio can be established between the changes in soil properties, especially in their agricultural chemical indices, and the yields obtained in the experiments. The greater yields correspond to the larger changes in the agricultural chemical indices taking place on thin peat-strongly- and medium-podzolic sandy loams with liming. The yields proved to be relatively larger than on cultivated peat-weakly- and medium-podzolic soils with a thicker peat horizon.

Especially large yields were obtained on strongly podzolized soils containing much mobile aluminum. On only slightly fertile soils with a thin peat horizon, small humus content, and a high content of mobile aluminum the increase in the yield of perennial grasses with liming was 60 to 70%. The maximum increase reached 180% (the V. I. Lenin collective farm, Vyru district).

TABLE 6

Effect of liming on bulk density

Location of experiment and description of soil	Year experiment set up	Year bulk density determined	Crop	Wt. of one liter of soil, grams[a]		
				No lime	Unit amt. of lime	Difference, g.
"Mooste" state farm; peat-medium-podzolic coarse clay loam	1948	1951	Barley	1296	1298	+2
		1952	Perennial grasses	1361	1265	−96
I. V. Stalin collective farm; peat-medium-podzolic clay loam	1949	1951	Rye	1416	1390	−26
		1952	Perennial grasses	1418	1349	−69
"Ruuza" state farm, Ryapina district; peat-medium-podzolic sandy loam	1948	1951	Perennial grasses, 3rd year of use	1388	1327	−61
"Bol'shevik" collective farm, Tartu district; peat-medium-podzolic sandy loam	1949	1951	Oats	1300	1237	−63
A collective farm, Ryapina district; peat-strongly-podzolic sandy loam	1949	1951	Oats	1281	1202	−79
"Tee Kommunizmile" collective farm, Tartu district; peat-strongly-podzolic sandy loam	1949	1952	Perennial grasses, 2nd year of use	1379	1299	−80
"Nygnaru" state farm, Tartu district; peat-weakly-podzolic coarse clay loam	1948	1952	Winter wheat	1383	1369	−14

[a] Average of four samples

On cultivated soils with a thicker peat horizon, richer in humus and containing little mobile aluminum, the average crop increment from liming was 10 to 15%, the maximum being 25%.

In the intermediate group of soils, with a peat horizon of average thickness and having intermediate podzolization (the "Uus Elu" collective farm and the "Mooste" and "Ruuza" state farms) the yield of perennial grasses increased in most cases after liming by about 30%; the maximum increase was 40% ("Mooste" state farm).

Thanks to the improvement in the physicochemical and physical conditions, the fertility of the soil is increasing, thus improving growing conditions for cultivated plants and soil microorganisms.

Conclusions

The study of changes in physical and physicochemical properties with liming of soils in the southern part of the Estonian SSR results in the following conclusions:

1. When applied to the basic types of peat-podzolic soils with different degrees of podzolization that are characteristic of the southern regions of the Republic, lime fertilizers in quantities equal to ½ and ¼ of the unit amount (as calculated on the basis of hydrolytic acidity) decrease the concentration of hydrogen ions and hydrolytic acidity and cause a number of other changes in the soil, assuring a medium favorable for the cultivation of plants. Such fractional quantities usually raise the soil pH (in KCl extracts) from 4.3–4.5 to 5.0, while unit amounts raise it to 5.5. Even comparatively small amounts of lime fertilizers cause a perceptible decrease in soil acidity.

2. The quantity of adsorbed cations, the cation exchange capacity, and the degree of saturation by cations all increase with liming. The quantity of adsorbed cations increases considerably with the use of amounts as small as one-fourth and one-half of the unit amount. The increase is particularly marked when the whole amount is applied. When relatively small amounts of lime fertilizers are applied to nonlimed acid soils, each centner of fertilizer causes a relatively larger increase in saturation of the soil by cations than when large amounts are applied. The use of whole unit amounts of lime fertilizer increases saturation to 70% and higher.

3. Mobile aluminum, toxic to cultivated plants, is eliminated by using half units of lime fertilizer. This is important for the slightly fertile peat-medium- and strongly-podzolized soils with a thin (less than 20 cm.) peat horizon.

TABLE 7

Effect of liming on the yield of field crops

Location of experiment and description of soil	Humus, %	Thickness of horizon A_1 in cm.	Year	Crop	Yield without lime, centners per ha.	Fraction or multiple of unit quantity of lime fertilizer							
						¼		½		1		2	
						Yield in centners per ha.	Yield increment, %	Yield in centners per ha.	Yield increment, %	Yield in centners per ha.	Yield increment, %	Yield in centners per ha.	Yield increment, %
V. I. Lenin collective farm, Vyrusk district; peat-strongly-podzolic sandy loam on clay loam	1.58	15–20	1948	Rye	13.0	—	—	14.7	12.8	14.5	11.5	14.9	14.3
			1949	Perennial grasses	37.7	—	—	54.3	43.9	58.2	54.5	65.1	72.6
			1950	same	9.2	—	—	20.6	124.6	21.9	138.1	21.5	134.4
			1951	Oats	10.3	—	—	14.2	38.3	15.0	46.1	15.7	52.5
			1952	Potatoes	140.0	—	—	148.0	5.7	152.8	9.1	157.6	12.6
			1953	Barley	5.7	—	—	14.7	157.9	15.5	171.9	19.4	240.3
"Tee Kommunizmile" collective farm, Tartu district; peat-strongly- and medium-podzolic sandy loam on clay loam	1.79	18–23	1950	Rye	24.1	24.4	1.6	25.5	6.1	27.5	14.2	28.0	16.3
			1951	Perennial grasses	14.3	23.0	60.8	24.7	73.1	29.1	103.5	32.1	124.5
			1951	Aftermath of perennial grasses	3.9	15.4	291.8	16.7	323.3	18.4	367.5	19.4	393.1
			1952	Perennial grasses	9.1	11.8	29.5	13.1	44.7	16.8	85.1	15.3	68.7
			1952	Aftermath of perennial grasses	2.9	9.4	218.7	10.8	268.7	14.0	137.2	13.3	352.0
			1953	Perennial grasses	14.0	14.0	0.0	16.2	15.8	13.2	−5.7	11.1	−20.7
"Uus Elu" collective farm, Tartu district; peat-medium-podzolic sandy loam on clay loam	1.84	20–23	1950	Rye	19.1	20.1	5.2	19.7	3.1	21.1	10.9	22.1	26.3
			1951	Perennial grasses	35.2	45.5	29.3	48.8	38.6	45.4	28.9	45.2	28.3
			1952	same	25.1	28.5	13.5	29.5	17.3	28.5	13.3	29.1	15.8
			1953	Winter wheat	9.7	9.3	−1.4	10.6	9.3	10.0	3.1	9.0	−7.2
"Kollino" state farm; Antslas district; peat-medium-podzolic coarse clay loam on clay loam	1.78	20–23	1949	Rye	16.4	—	—	16.8	2.4	16.7	2.0	17.4	6.2
			1950	Perennial grasses	37.3	—	—	41.0	9.9	43.3	16.0	44.7	19.7
			1951	same	28.9	—	—	30.1	4.1	28.7	−0.8	33.6	16.0
			1952	same	27.2	—	—	31.5	16.0	33.8	24.4	34.8	28.0
"Luun'ya" state farm, Tartu district; peat-weakly-podzolic coarse clay loam on clay loam	2.32	20–30	1949	Spring wheat	15.1	—	—	15.9	5.9	16.4	8.8	16.8	11.2
			1950	Vetch-oat feed mixt.	17.4	—	—	20.5	17.9	19.9	14.4	19.8	13.9
			1952	Perennial grasses	47.8	—	—	55.3	15.6	55.9	17.0	52.9	10.6
			1953	same	48.7	—	—	47.3	−2.3	48.8	0.2	48.7	0.0

4. There is an increase in the available phosphorus of the soil when limed; this increase is more conspicuous in the fourth to sixth years after liming.

Liming also substantially increases soil nitrates. During the period of middle summer the difference in the nitrate content on limed and nonlimed plats reached 10 to 15 mg. per kg. of soil.

5. Liming was favorable to water relations on all types of soils studied, increasing infiltration of clay loams and decreasing that of coarse sandy loams.

Application of lime fertilizers improves permeability of soil to air, showing an improvement in its structure. In fine-textured soils the permeability to air increases, while in coarse-textured soils it decreases.

Permeability both to air and to water is more pronounced when liming is combined with the cultivation of perennial grasses.

6. The bulk density of the soil, which depends directly on its structure and on the amount of roots present, decreases by an average of 60 t 70 g. per liter of soil after liming.

7. Grain yields average 15 to 20%, and perennial grasses from 20–30 to 80–100%. The highest yields occur on soils with low fertility an humus content.

8. It is better in practice to apply half quantities of lime fertilizers (5 to 6 metric tons pe hectare of burnt lime), since they significantl improve soil properties and give relatively larg yields as compared with those resulting fro unit or double quantities.

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PLANT NUTRIENTS IN STRUCTURED SOILS

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THE concept that structured soils have a better nutrient status than structureless soils is inadequately supported by experimental data. In general, this concept is based on the fact that structured soils have more favorable air and moisture properties which encourage intensification of microbiological activity. According to this concept, structured soils have a more harmonious combination of aerobic and anaerobic decomposition of organic matter, which also affects the optimal nutrient conditions for plants.

The following are the results of some of our research on this subject. We make no claim to have solved this large and complex problem, but we believe that the studies have clarified certain aspects of nutrient conditions occurring in structured soils. These results may serve as an incentive for deeper study of the question as a whole with respect to the unique characteristics of individual types of soils and physicogeographic zones.

The material used was the ordinary low-humus chernozem of the Bezenchuk Experimental Station. A differentiated study was made of the unique characteristics of the nutrient conditions of its individual structural fractions and the reaction of plants to these characteristics.

Pot Experiments

Pot experiments with barley were set up in 1955 to test the reaction of plants to different levels of fertility in separate structural fractions. Soil was taken on June 20 from an area adjoining the Station; this area had not been tilled for the past four years and had become overgrown. The soil moisture was 4 to 5%. We used three structural fractions: 5 to 7 mm., 2.5 to 3 mm. and 1 to 1.5 mm. The largest and smallest fractions were studied in two treatments: with whole, undisturbed clods, and with pulverized samples. Controls consisted of whole soil taken without separation into fractions but with rubbing and sifting through a sieve with 3 mm. openings. The experiment was set up in Vagneroff pots with a soil capacity of 6 kg. each. It was replicated three times. No fertilizers were applied at the beginning of the experiment. During growth of the plants—at the time of culming—small supplementary applications of complete mineral fertilizers were made in small quantities (46 to 47 mg. per kg. of soil) in the form of ammonium nitrate, potassium nitrate, and di-ammonium phosphate. The soil was watered with tap water to 60% of the capillary moisture capacity.

Sprouts appeared on June 25. As early as the third day after sprouting distinct differences were detected among the treatments. Plants grew better on the pulverized whole soil and on the pulverized fractions than on the intact structural fractions. As soon as tillering began, the plants on the pulverized fractions showed signs of nitrogen deficiency (pale green color, yellowing of the tips, delay in tillering), while the plants which had developed on the undisturbed structural fractions gradually began to catch up with them. The finer the clods, the earlier was the beginning of improvement in the plants grown on them. This is illustrated by data from measurement of the height of the plants, the "energy of tillering" (rate of formation of shoots), and the weight of 100 plants when dug up (Table 1).

Data on yields for this experiment are given in Table 2.

The yield in grain and straw on individual fractions proved to be lower than on the whole soil which had been rubbed through a 3 mm. sieve. The yield in grain and straw decreased as the size of the clods increased (treatments 2, 4 and 5). Pulverizing the clods increased the grain yield (treatments 2 and 3, 5 and 6) both on the large (5 to 7 mm.) and small (1 to 1.5 mm.) clods, while the yield in straw increased on the large fraction. From this it follows that the higher yield of grain and straw on the non-fractionated soil is caused by two factors: the presence in the soil of the smallest and most fertile fractions (<1 mm. in diameter) and destruction of the large clods.

The raised level of plant nutrition in pulverized soil and on the small fractions in the initial phases caused the higher energy of productive tillering and greater spike size (see the number of spikelets per spike) on the earliest formed

TABLE 1

Dynamics of plant growth and development (average of three replicates)

Treatment No.	Treatment (fraction, mm.)	Height of plant, cm.				Energy of tillering		Moist wt. of 100 plants in gm., 7/9
		6/29	7/9	7/19	7/29	7/19	7/29	
1	Whole soil, pulverized	9.5	24.5	29.6	46.9	2.2	3.4	65.7
2	5–7 whole clods	6.9	21.4	26.3	40.6	1.4	3.6	45.9
3	5–7 pulverized clods	9.3	24.0	29.2	39.2	1.3	3.4	48.7
4	2.5–3 whole clods	7.1	21.2	25.0	39.8	1.7	3.5	54.4
5	1–1.5 whole clods	6.3	21.7	27.7	39.4	2.1	3.5	51.7
6	1–1.5 pulverized clods	8.3	24.5	30.0	42.5	2.1	4.2	65.3

TABLE 2

Barley yield on different structural fractions and on structureless soil (expressed in grams per pot; average of three replicates[a])

Treatment No.	Treatment (fraction in mm.)	Grain yield	Straw yield	Characteristics of harvest			
				Energy of productive tillering	Number of spikelets per spike		Thousand-grain wt.
					Main stem	Side stems	
1	Whole soil, pulverized	13.1	27.5	3.9	11.8	11.1	38.5
2	5–7 whole clods	8.9	17.6	3.3	8.9	9.3	37.3
3	5–7 pulverized clods	10.5	23.8	3.5	7.7	10.0	38.7
4	2.5–3 whole clods	9.0	17.9	3.5	9.5	8.6	37.5
5	1–1.5 whole clods	9.8	19.1	3.8	10.6	7.6	38.0
6	1–1.5 pulverized clods	11.1	17.4	4.0	11.3	7.5	41.0

[a] Standard error of the mean (m) ±0.454 ± 0.417
Error of experiment (md.) ±0.642 ± 0.589

main stalks. Furthermore, the larger the clods, the greater the size of the spikes on the secondary stalks that were formed later, and the later the development and maturation of the plants. However, the total yield in grain and straw proved to be higher on the small clods and pulverized fractions (but for straw, on the large ones), for these assured better nutrition of the plants before the beginning of tillering (and the beginning of differentiation of embryonic spikes on the main shoots). The thousand-grain weigh increased in inverse proportion to the size of th clods and also was higher on the pulverized soil than on the non-pulverized.

Thus, two periods may be clearly designate in the growth and development of plants o structured soil: the initial period (preceding tillering), when the soil structure retards th growth and development of the plants, and th subsequent period, when the plants on structured soil with adequate moisture begin to develop better than on structureless, pulverize soil. The larger the aggregates, the later the beginning of improvement in the growth and development of the plants.

The question of the comparative level of fertility of structured and structureless soils wa studied by K. N. Zaitsev at the Bezenchuk Experiment Station under irrigated field condition in 1939 and 1940. Spring wheat gave the following yield of grain (in centners per hectare):

	1939	1940	mean
Natural soil	31.0	30.0	30.5
Structured soil (1–7 mm.)	29.0	30.7	29.8
Pulverized soil (<1 mm.)	30.0	29.4	29.7

No difference was detected between structure and structureless soils. However, the condition of the field experiments themselves actuall smoothed out the effect of the presence or absence of structure. Irrigation and the first cultivation of the soil brought about partial pulverization of the artificially created soil structur (treatment 2), and at the same time there wa aggregation of the artificially pulverized soil. A early as 15 days after the division of the soil int aggregates and silt, analysis of the aggregate after the first irrigation and mellowing showe the following: In the structured soil 20% of th aggregates had fallen apart into smaller fraction and silt, while 75% of the pulverized soil ha aggregated. By spring of the next year the aggregate composition of the structured soil ha become identical to that of the natural soil. Under these conditions the lack of any difference between the crops on structured and pulverize soils becomes understandable.

Fertility Factors of Structured Soils

The characteristics of growth, developmen and final productivity of plants on differen fractions of structured soils, established in the pot experiments cited previously should be

TABLE 3

Agrochemical indices of individual structural fractions (average of four determinations on each fraction)

Fraction in mm.	NH_4	NO_3	Acetate-soluble P_2O_5	Available K_2O	Hydrolytic acidity	Total adsorbed cations	% saturation by cations	Humus, % (Tyurin's method)	pH of KCl extract
	mg./kg. of oven-dry soil		in mg./100 gm. of soil		meq./100 gm. soil				
7–10	22	95	16.5	15.1	0.74	36.4	98	5.37	7.2
5–7	39	93	24.4	19.2	0.79	36.4	98	5.25	7.2
3–5	115	92	45.9	19.2	0.87	36.3	98	5.16	7.2
2–3	41	95	48.6	22.9	0.88	34.9	97	5.43	7.3
1–2	20	112	54.1	25.2	0.96	34.8	97	5.09	7.2
0.25–1	47	159	43.6	18.3	0.70	34.1	98	5.00	7.2
Whole soil	21	92	38.0	15.1	0.63	36.2	98	5.57	7.2

largely attributed to the specific peculiarities of the nutrient conditions occurring in these soils (inasmuch as the other element of soil fertility—the water relations—was optimal in all cases).

Table 3 shows the results of determining some of the basic agrochemical characteristics of the nutrient status of individual structural fractions of a typical chernozem. The soil for the analyses was taken in spring (May 10, 1955) from the same area as for the pot experiments (overgrown for four years) on the second day following a 24-hour rain which had been preceded by a prolonged dry period (only 4 mm. of rain fell throughout April and the soil was very dry). The moist soil (moisture 18.61%) was put through an appropriate set of sieves and the nitrate and ammonia contents were immediately determined (the remaining determinations were carried out after the soil had been air-dried). In this way we preserved all the conditions existing in the pot experiments (the dried soil was gradually moistened to optimal moisture content after it was packed in the pots). Ammonia was determined colorimetrically by Nessler's reagent in a KCl extract, nitrates by 2,4-phenol disulfonic acid, phosphates soluble in 0.5 N acetic acid by Malyugin and Khrenova's method and phosphates soluble in ammonium carbonate solution by Das and Machigin's method, potassium by Brovkina and Peive's method, humus by Tyurin's method, and total adsorbed cations and hydrolytic acidity by Kappan's method.

Table 3 shows that with a change in the fraction size there is a regular pattern of change in the indexes of fertility; negligible deviations from the general pattern should be ascribed to individual peculiarities of the sample.

The content of available forms of the fundamental components of plant nutrition (nitrates, acetate-soluble phosphorus and available potassium) decreases as the clods increase in size. The content of ammonia nitrogen, on the other hand, increases with an increase in size of the clods, and it is only in the largest fractions (>5 mm. in diameter) that any decrease in it is noted. This is related to the rate of the nitrification process; when it decreases the ammonia content rises, but with a stable level in the largest clods (5 to 10 mm.) the NH_4 content falls. The opposite pattern was observed for the content of phosphorus extractable in ammonium carbonate solution (by Das and Machigin's method): in 3 to 5 mm. clods it was 4.31 mg., in 2 to 3 mm. clods 3.54 mg., in 0.25 to 1 mm. clods 3.21 mg., that is, the phosphorus increased as the size of the clods increased.

Under these conditions, because the soil is structured results in the conversion of the most available forms of the nutrients to forms less available to plants; this takes place to a greater degree as the aggregates increase in size. As the clods grow larger, the hydrolytic acidity of the soil decreases (except in the 0.25 to 1 mm. fraction), and the sum of the adsorbed cations and the degree of saturation with cations increases. In these soils no regular change in the pH by fraction was found.

The individual structural fractions have higher indexes than does non-fractionated soil (treatment 7) with respect to ammonia and nitrate nitrogen, available potassium and hydrolytic acidity, and lower indexes for degree of saturation of the soil by cations, humus, and in part, for the total of adsorbed cations. As to phosphorus content, the non-fractionated soil shows a value which is about average for the structural fractions of different sizes. This relationship exists because the non-fractionated soil contains not only all the structural fractions between 0.25 and 10 mm. in diameter, but also two extreme fractions, one <0.25 mm. and one >10 mm. The first of these is present in only negligible quantities in the investigated soils—about 0.06% of the total soil weight—and does not exert any effect on the mean values of the indexes, while the second (large clods) amounts to a substantial proportion—17.41%. This causes a further decrease in the non-fractionated soil of the available components of nutrition (ammonia and nitrate nitrogen and available potassium) and in hydrolytic acidity as well as an increase in humus content and in part of the total adsorbed cations and degree of saturation with cations.

The differences noted may be explained by the direct effect of two factors: the value of the specific surface area and the degree of aeration. As the size of the clods increases their specific surface area decreases, and inasmuch as the reactive capacity of soil is a direct function of its specific surface area, it is natural to expect a decrease in the formation of the available components of plant nutrition as the size of the aggregates becomes larger. At the same time, the formation of larger aggregates results in an intensification of anaerobiosis in the soil and a decrease in the aerobic microbiological processes. This leads to the same results and explains the increase in organically bound nutrients as the clods grow owing to inhibition of the decomposition of organic matter.

The increase in content of humus and of total adsorbed cations and the decrease in available forms of phosphorus and potassium in the larger clods are related to an increase in their smallest sized particles (<0.01 mm.), as confirmed by particle size analyses of the individual structura fractions (Table 4).

TABLE 4

Particle size analysis of structural fractions in percent

Treatment No.	Structural fraction in mm.	Medium and fine sand (<0.05 mm.)	Coarse silt (0.01–0.05 mm.)	·Medium silt (0.005–0.01mm)	Physical clay (<0.01 mm.)
1	7–10	26.0	27.5	33.4	46.5
2	5–7	22.0	31.5	32.5	46.5
3	3–5	28.0	25.7	31.8	46.3
4	2–3	29.0	35.4	22.9	35.2
5	1–2	26.0	36.4	19.5	37.6
6	0.25–1	28.0	44.4	25.3	27.6

These changes in the texture of the structura fractions lead to increasing compactness of the clods as their size increases, to a slackening of the aerobic processes within the clod, and to a decreased rate of decomposition and an increased rate of accumulation of humic substances bound to the soil. At the same time the adsorbing complex of the larger fractions grows larger and the fixation of phosphorus and potassium increases.

Having explained the characteristics of the nutrient status formed in structural fractions of different sizes under moist and dry conditions we can explain the results of pot experiment No. 1. The fact that plants grow better in the initial period on pulverized rather than on structured soil is explained by the significant increase in specific surface area of the pulverized soil and the greater contact of plant roots with the soil; mechanical destruction of the aggregates results in a substantial increase in the content of the available nutrients. The improvement in development of the plants on structured soils which occurs by the time of tillering—judging by a number of indexes (intensification of tillering, deeper green color, less yellowing at the top) and taking into consideration the uniformly optimum moisture level in all the treatments—must be attributed to the mobilization of the basic nutrients, mostly nitrogen, within the clods, resulting from an intensification of microbiological activity. This is also suggested by the nitrogen content of the plants which, when they were dug up on July 9, amounted to 5.70, 5.04, 4.45, 4.51, 5.66 and 5.08% by dry weight in treatments 1 to 6, respectively. By the beginning of tillering the maximal amount of nitrogen was contained in plants from the soil which included all the structural fractions, including the microstructural elements, rubbed through a 3 mm. sieve (treatment 1) and also from the soil with the finest structural fraction (treatment 5). The somewhat smaller percentage of nitrogen in treatment 4 (2.5 to 3 mm. clods) than in treatment 2 (5 to 7 mm. clods) is explained by the greater weight of the plants in treatment 4 than of those in treatment 2 (see Table 1). Calculation of the amount of nitrogen contained in a single plant shows that it decreases at the same time that the clod size increases. For the 1 to

1.5 mm. fraction (treatment 5) the plant absorbed 3.93 mg. of nitrogen, in the 2.5 to 3 mm. fraction (treatment 4) it was 3.56, and in the 5 to 7 mm. fraction (treatment 2) it was 3.21 mg. of nitrogen. The nitrogen content of plants from intact clods at this time was higher than that of plants from pulverized clods (compare treatments 2 and 3, and also 5 and 6). The greatest depletion of nitrogen reserves was observed in pulverized clods that had been 5 to 7 mm. in diameter (treatment 3) and which, in the initial period, had assured the best growth.

To ascertain the correct explanation for the changes noted in the growth and development of the plants, we also traced the changes taking place in the soil. So we set up a small auxiliary experiment with barley shoots (sowed July 16) which were harvested at one month, that is, at the moment when improved growth was noted in the plants on the larger structural fractions. In [the other part of] this experiment we used the same treatment without the plants (fallow soil). The development and yield of the shoots are shown in Table 5.

TABLE 5

Development and yield of shoots on structural fractions of different sizes[a]

Treatment No.	Fraction in mm.	Height of plants in cm.					Fresh weight in grams	
		7/22	7/27	8/5	8/10	8/16	Above-ground part	Roots
4	5–7	11.3	15.2	16.9	18.3	19.8	2.91	0.67
5	2–3	11.4	16.2	18.0	20.0	21.7	3.74	1.37
6	0.25–1	12.7	17.7	18.2	19.3	20.7	3.47	1.48

[a] Standard error of the mean (m) ±0.151
Error of experiment (md) ±0.212

As in the original pot experiment, after better initial growth on the finest structural fractions with slowing of growth in proportion to the size of the structural fractions, an improvement was noted by the beginning of tillering in the growth on the coarser fractions, and suddenly (August 10) the plants on the 2 to 3 mm. fraction overtook those on the fine fractions in growth. By harvest time an improvement in growth was noted on even the largest (5 to 7 mm.) fraction, on which the height of the plants had begun to approach that of the plants on the finest fraction.

Before setting up this auxiliary experiment and also at the time of harvesting the plants from it, the soils were analyzed for their content of basic nutrients. The results are shown in Table 6.

Table 6 shows that the original content of the basic nutrients in the individual structural fractions recapitulates a familiar picture: an increase in the content of nitrate nitrogen, acetate-soluble phosphorus, and available potassium and a decrease in the content of ammonia nitrogen and ammonium-carbonate soluble phosphorus as the clods decrease in size. During fallowing there was an abrupt increase in the content of nitrates and, in part, of available potassium in

TABLE 6

Content of basic nutrients in the soils with plants

Fraction in mm.	NO_3		NH_4		Acetate-soluble P_2O_5		Ammonium carbonate P_2O_5		Available K_2O	
	In mg. per kg. of oven-dry soil				In milligrams per 100 grams of soil					
	At beginning	After harvest	At beginning	After harvest	At betinning	After harvest	At beginning	After harvest	At beginning	After harvest
In fallow soil										
5–7	15.0	161.2	31.2	37.5	17.3	19.5	5.7	5.8	15.2	27.1
2–3	19.0	202.5	22.1	27.1	25.8	15.4	5.5	5.5	25.3	35.9
0.25–1	23.6	145.0	12.1	26.2	33.0	19.6	5.0	5.4	28.1	35.9
In soil with plants										
5–7	15.0	16.2	31.2	28.2	17.3	12.7	5.7	4.8	15.2	17.0
2–3	19.0	15.3	22.1	23.8	25.8	12.2	5.5	4.7	25.3	24.0
0.25–1	23.6	15.2	12.1	22.4	33.0	16.7	5.0	4.7	28.1	24.7

all fractions; there was relatively less change in the content of phosphorus and of ammonia nitrogen as a result of its use in nitrification. The maximal nitrate content was found in the intermediate fraction (2 to 3 mm.); there was a significant increase—of more than 10 times—in the nitrate content of the largest fraction (5 to 7 mm.); the smallest increase (6 times) in the amount of nitrates took place in the finest fraction (0.25 to 1 mm.). The increase in potassium was also larger in the larger aggregates. In general, the relationships of ammonium carbonate-soluble phosphorus existing before fallowing were retained. The ammonia content after fallowing not only did not decrease but it even increased somewhat, which, considering the intensified nitrification taking place, shows the simultaneously unweakened ammonification taking place. A somewhat larger proportional increase in ammonia in the finest fraction should be related to a decrease in the nitrification rate.

The content in the different structural fractions of nitrate nitrogen and of acetate-soluble phosphorus had changed by harvest time to correspond to the rate of growth of the plants, and, therefore, with the amount of nitrogen and phosphorus absorbed in the different treatments. The content of ammonium carbonate-soluble phosphorus and of potassium and ammonia in general changed little; there was only a certain relative increase in the ammonia (as in the fallow soil) in the finest fraction (0.25 to 1 mm. in connection with decrease in nitrification rat in it. Thus, in the pot experiment the improvement in growth and development of the plant that began by the onset of tillering, first in th finest and then in all the larger structural fractions, is to be explained by the gradually increasing (from the fine fractions to the coars ones) rates of mobilization of the basic nutrients, primarily in the nitrification rate.

These facts show the ability of structured soils under fairly stable moisture condition (that is, in fallow) to supply plants with their basic nutrients, unaffected (or less affected) by the size of the aggregates, thus assuring norma growth of the plants. This was confirmed by a special experiment with barley shoots grown on soil taken from fall fallow in early spring (at the beginning of May); when the soil had not yet been subjected to drying. The experiment was replicated twice in two series: first with the original moist soil, and second with the same soil which had previously been dried. The original soil moisture in percent was:

	Whole soil	5–10 mm.	1–5 mm.	0.25–1 mm.
Moist soil	26.55	27.21	26.23	22.47
Dry soil	8.98	7.48	7.36	6.74

The initial nitrate content in the moist soil (in mg. per kg. of oven-dried soil) was: in whole soil, 14.6; in the 5 to 10 mm. fraction, 13.7; in the 1 to 3 mm. fraction, 13.1; in the 0.25 to 1 mm. fraction, 12.9. Mixtures of the structural fractions used in the individual treatments of the experiment were made up of clods of different sizes in the following percentages:

Structural mixture	5–10 mm.	1–5 mm.	0.25–1 mm.
Coarse clods	75	16.7	8.3
Medium clods	12.5	75	12.5
Fine clods	8.3	16.7	75

Sowing took place May 26. All pots were watered uniformly to 60% of the capillary moisture capacity. The harvest was June 20. Results are shown in Table 7.

Table 7 shows that on the originally moist soil the development of plants on pulverized clods at first lagged behind that on structural aggregates and did not begin to take even a slight lead until after the first ten days. The yield in shoots on the structured soil did not differ from that on pulverized soil; on the medium-clod struc-

TABLE 7

Effect of previous drying of the soil on the development of barley shoots on pulverized and structured soils[a]

Treatment No.	Treatment	Height of plants, cm.				Fresh weight of crop, gm.
		6/5	6/10	6/15	6/20	
	A. Original soil, moist					
1	Whole pulverized soil	8.4	14.4	14.6	15.4	3.6
2	Coarse clods, whole	8.5	12.6	14.2	16.1	4.1
3	same, but pulverized	8.0	13.3	15.0	16.2	4.1
4	Medium clods, whole	8.3	12.7	14.3	17.6	4.7
5	same, but pulverized	7.8	13.5	14.5	16.8	4.1
6	Fine clods, whole	7.4	11.2	12.8	14.8	4.1
	B. Original soil, dry					
1	Whole pulverized soil	8.8	14.4	15.2	17.0	5.0
2	Coarse clods, whole	9.1	14.3	15.0	18.1	5.2
3	same, but pulverized	10.0	16.9	17.1	19.4	5.9
4	Medium clods, whole	9.2	15.8	16.8	19.2	5.8
5	same, but pulverized	9.9	16.9	17.0	19.9	6.9
6	Fine clods, whole	8.6	15.4	16.0	18.3	5.7

[a] Standard error of the mean: ±0.237

tural mixtures the plants developed somewhat better than in the other treatments.

In all treatments the plants developed better on soils which had previously been subjected to drying than on undried soils. Just as in the pot experiments (see Table 1), the plants from the very first grew better on pulverized soil than on structured soil. The yield in shoots was also higher here. At ages as young as two weeks (June 14) a lighter color and yellowing of the tops was detected in the plants on pulverized soils and the finer fractions. We noted similar characteristics in the basic pot experiment.

Thus, previous drying of the soil is a critical factor in determining the difference in the level of fertility between pulverized and structured soils: moist pulverized and structured soils assure the plants of more or less uniform nutrients during the initial period of their growth; drying (and subsequent moistening) increase fertility of the pulverized soils during the initial period of plant growth as compared to structured soils. This is of great importance in arid regions where the precipitation during the growing period very often falls on extremely dry soil.

The positive effect of drying of the soil on its fertility was first established by the investigations of A. N. Lebedyantsev. They showed that drying and subsequent moistening substantially raised the content of nitrates, ammonia, and other available compounds in a manner similar to that occurring in soil following its sterilization. These investigations were confirmed by many authors, but only for whole soil; none of the individual components of the soil (different structural and textural fractions) was studied in this respect.

One can imagine that in the different-sized structural fractions the process occurs in the following way: After drying (or sterilizing) of the soil and its remoistening, the activity of its microorganisms is reestablished, or even intensified, unevenly in different fractions. Initially, activity of the microorganisms is limited by the total surface area of the clods. The fine fractions, having a higher specific surface area, cause more intensive development of the microflora and consequently more ammonia, nitrates and other available compounds are formed on them than on coarser fractions. In proportion to the increase in numbers and activity of the microorganisms taking place under conditions of optimal soil moisture, gradual penetration of the microorganisms from the periphery to the interior of the clods takes place. Since the coarser clods contain more humus, organically bound phosphorus, and other compounds, they offer more favorable conditions for the vital activities of microorganisms. Consequently, the production of ammonia, nitrates, and other nutrients becomes the same as in the fine fractions and even begins to surpass that of the latter. This explanation is only a working hypothesis and needs specific confirmation by microbiologists.

Conclusions

1. The fertility of structured soil is not uniform. With an increase in the size of clods (after drying and remoistening) there is a decrease of the most available forms of nutrients for plants —nitrates, phosphorus and potassium; an increase in their ammonia content (in clods up to 5 mm. in diameter); and an increase in the total adsorbed cations and degree of saturation with these cations in the larger clods as hydrolytic acidity decreases.

2. Differences in the quality of clods of different sizes cause an uneven degree of fertility and, under the conditions of the pot experiment, dried and remoistened pulverized soils assure better initial growth of plants than do structured soils. The coarser the structure of the aggregate, the weaker the initial growth of the plant.

3. With adequate moisture in the pot experiment, structured soils from the beginning of tillering show intensified mobilization of the available plant nutrients, primarily nitrogen, and the development of plants on them improves noticeably. The smaller the size of the structural aggregates, the earlier the mobilization of nutrients occurs. The finer clods give a larger yield of grain and straw and more full-weight grain than do the coarser clods. As the clods become coarser the number of shoots at tillering increases, maturation is delayed and the growing period protracted.

4. When structured soils are left in fallow in the presence of adequate moisture and the absence of overdrying of the clods their nutrient content improves considerably and the initial growth of plants on them is the same as on pulverized soils.

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Announcements

MEETING OF DELEGATES OF THE ALL-UNION SOCIETY OF SOIL SCIENTISTS

A meeting of the delegates of the All-Union Society of Soil Scientists has been called for May, 1958, in Moscow.

Participants in the work of the meeting will be the delegates with voting rights chosen at general conventions of the branches and divisions of the All-Union Society of Soil Scientists in the proportion of one delegate for every ten members of the Society.

The meeting is being called to decide the following organizational questions: confirmation of the new constitution of the Society; the account of the organization committee of the Society; election of the council of the Society and the inspection committee. In addition, consideration will be given at this meeting to the following scientific problems:

1. Regular current tasks of soil scientists of the USSR with respect to the decisions of the party and the government;
2. Classification of soils and soil productivity;
3. Soil regionalization;
4. Soil factors in the effectiveness of soil fertility;
5. Types of soil erosion processes, their occurrence in the USSR and measures for their control.

The principal reports on these problems will be heard at the plenary sessions; supplementary reports will be heard in the four sections now being organized:

a. Genesis, geography and classification of soils;
b. Regionalization and productivity of soils;
c. Soil fertility;
d. Improvement and control of soil erosion.

After the meeting there will be a field trip along the main road from Moscow to Kursk for a discussion under field conditions of questions of the genesis and classification of soils.

Organization Committee,
All-Union Society of Soil Scientists

ANNOUNCEMENT OF THE V. V. DOKUCHAYEV PRIZE CONTEST

The office of the Division of Biological Sciences, Academy of Sciences, USSR, announces the 1958 V. V. Dokuchayev Prize Contest (20,000 rubles). The award is to be given for the outstanding scientific paper in the field of soil science.

The competition is open to individual authors or to groups.

Only published papers (in triplicate) should be submitted. They should be sent to the Division of Biological Sciences, Academy of Science, USSR (Leninskii Prospekt 14, Moscow). Closing date is July 1, 1958. A summary of the documents to be submitted in the competition is given in the newspaper Izvestiya, No. 6 (12622), January 8, 1958.

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The AIBS is in the process of expanding its Russian Translations Program extensively. Funds to subsidize translation and publication of important Russian literature in biology have been obtained from the National Science Foundation, as part of a larger program to encourage the exchange of scientific information between the two countries. The following monographs have been scheduled for publication:

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